

External Technical Review of System Planning for Low-Activity Waste Treatment at Hanford



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TABLE OF CONTENTS

List of Tables.....	v
List of Figures.....	vi
Abbreviations and Acronyms.....	vii
Executive Summary	x
External Technical Review of System Planning for Low Activity Waste Treatment at Hanford .	1
1.0 Background	1
2.0 Scope of the Review	3
3.0 Team Membership	3
4.0 Lines of Inquiry	3
5.0 Overview of Key Programmatic Issues and Decisions	5
6.0 Results and Discussion	6
6.1 ORP Systems Plan, Strategy, and Approach	6
ORP Systems Plan	6
ORP Strategy	7
Timeline for Key Decisions	8
Hanford Tank Waste Operations Simulator (HTWOS).....	9
6.2 Uncertainties that Impact Program Needs, Schedule, and Cost.....	10
Administrative and Program Management Uncertainties.....	10
Technical Uncertainties	11
6.3 LAW Processing Requirements.....	13
LAW Capacity and Performance Requirements.....	13
Capacity and Performance Requirements for Interim and Supplemental Pretreatment	15
Uncertainty in the Amount of Sodium to be Treated.....	18
Options for Reducing the Amount of Sodium to be Treated	19
The Waste Treatment Plant Leaching Process.....	19
Modified Bayer Process	20
Caustic Management Aluminum Removal (Lithium Precipitation) Flowsheet ...	20
Continuous Sludge Leaching Process	21
Electrochemical Salt-splitting Process.....	21

	Fractional Crystallization.....	22
6.4	Initiating LAW Processing Prior to WTP Completion (Early LAW).....	23
6.5	Interim and Supplemental Pretreatment Needs and Options	25
	Technology Options for Providing Interim and Supplemental Pretreatment	25
	Solids Separation	26
	Fractional Crystallization.....	27
	Modular Caustic Side Solvent Extraction Unit.....	27
	Cesium-137 Separation	28
	Crystalline Silico-titanate Process	28
	Resorcinol Formaldehyde Process	29
	Strontium/Actinide Separation.....	29
6.6	Options for Increased WTP LAW Melter Capacity	30
	WTP 3rd LAW Melter Option.....	31
	Two Enhanced WTP LAW Melters Option.....	33
6.7	Bulk Vitrification	36
6.8	Second LAW Facility	38
6.9	Variants of WTP LAW Vitrification	39
6.10	TRU Processing and Disposition	39
6.11	ORP Cost Estimates	40
	Analysis of the Cost Estimates	40
	Cost Trade-Offs Between LAW and HLW Treatment	41
6.12	Comparative Schedule and Financial Analysis of Selected Scenarios by Review Team	41
	The 60,000 MT Sodium Assumption.....	46
	The 90,000 MT Na Assumption	49
	Observations	52
7.0	Conclusions and Recommended Priorities.....	53
8.0	References	58
	Appendix A – Biographies of Review Team Members.....	62
	Appendix B – External Technical Review Charter.....	64

LIST OF TABLES

Table ES-1. Summary Level Comparison of Results From Evaluation of Four Scenarios and Associated Variants	xviii
Table 1. Comparison of Cesium-137 Removal Requirement for LAW Pretreatment at WTP (Hanford) and SWPF (Savannah River)	17
Table 2. Sodium Sources, Amounts, and Planned Dispositions or Uses ...	19
Table 3. Fractional Crystallization Results	23
Table 4. Comparison of Cross-Flow and Rotary Microfilters	26
Table 5. Preliminary Rotary Microfilter Test Results	27
Table 6. The Four Scenarios	44
Table 7. Estimate: Present Worth of Expected Future Costs with Associated WTP Mission Durations and Completion Dates (60,000 MT Na Assumption)	47
Table 8. Interval Estimates of the Present Worth of Expected Future Costs (60,000 MT Na Assumption)	47
Table 9. Estimate: Present Worth of Expected Future Costs with Associated WTP Mission Duration and Completion Dates (90,000 MT Na Assumption)	49
Table 10. Interval Estimates of the Present Worth of Expected Future Costs. The 5 th and 95 th Percentiles of the 90 Percent Credibility Interval (90,000 MT Na Assumption)	50

LIST OF FIGURES

Figure 1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rate	1
Figure 2. Simplified Hanford Tank Waste Treatment and Immobilization Flow Diagram	2
Figure 3. Currently Projected Timeline for Key Programmatic Milestones	8
Figure 4. Illustration of Relationship Between Total Net Vitrification Capacity and Treatment Duration	15
Figure 5. Interval Estimates of the Present Worth of the Expected Future Costs; 90 Percent Credibility Interval (60,000 MT Na Assumption)	48
Figure 6. Interval Estimates of the Present Worth of the Expected Future Costs: 90 Percent Credibility Interval (90,000 MT Na Assumption)	50

ABBREVIATIONS AND ACRONYMS

ALARA	As Low As Reasonably Achievable
ARP	Actinide Removal Process
ART	Advanced Remediation Technology
BCI	Building Cost Index
BNFL	British Nuclear Fuels Limited
BNI	Bechtel National, Inc.
BOF	Balance of Facilities
BV	Bulk Vitrification
CCI	Construction Cost Index
CE	Cost Estimate
CEPCI	Chemical Engineering Plant Cost Index
CHG	CH2M HILL Hanford Group
Ci/gal	Curies/gallon
Ci/L	Curies/Liter
CS	Cast Stone
CSSX	Caustic Side Solvent Extraction
CST	Crystalline Silico-titanate
CY	Calendar Year
DF	Decontamination Factor
DOE	Department of Energy
DST	Double-Shell Tank
DWPF	Defense Waste Processing Facility
EM	Office of Environmental Management
EMAAB	Environmental Management Acquisition Advisory Board
FS	Full Scale
FTE	Full-Time Equivalent
FY	Fiscal Year
HEPA	High-Efficiency Particulate Air
HLW	High-Level Waste
HTWOS	Hanford Tank Waste Operations Simulator
HQ	Headquarters
HVAC	Heating, Ventilation, and Air Conditioning
ICV	In Container Vitrification

IDF	Integrated Disposal Facility
ILAW	Immobilized LAW Vitrified Waste
IPS	Interim Pretreatment System
LANL	Los Alamos National Laboratory
LAW	Low-Activity Waste
LMI	Logistics Management Institute
LOI	Lines of Inquiry
LWO	Liquid Waste Operations
MCU	Modular Caustic Side Solvent Extraction Unit
MT	Metric Tons
MTG/day	Metric Tons of Glass/Day
NEPA	National Environmental Policy Act
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORP	Office of River Protection
PEP	Pretreatment Pilot Plant
PUREX	Plutonium-Uranium Extraction (Plant)
REDOX	Reduction and Oxidation Facility (S-Plant)
RF	Resorcinol Formaldehyde
ROM	Rough Order of Magnitude
RPP	River Protection Project
SR	Steam Reforming
SRS	Savannah River Site
SST	Single-Shell Tank
SWPF	Salt Waste Processing Facility
TC & WM EIS	Tank Closure and Waste Management Environmental Impact Statement
TFCOUP	Tank Farm Contractor Operations and Utilization Plan
TPA SST	Tri-Party Agreement Single-Shell Tank
TRU	Transuranic
UK	United Kingdom
WIPP	Waste Isolation Pilot Plant
WTP	Waste Treatment and Immobilization Plant

WTP HLW	Waste Treatment and Immobilization Plant—High-Level Waste
WTP LAW	Waste Treatment and Immobilization Plant—Low-Activity Waste
WTP PT	Waste Treatment and Immobilization Plant Pretreatment
WVDP	West Valley Demonstration Project
WVNS	West Valley Nuclear Services

EXECUTIVE SUMMARY

BACKGROUND

The DOE Hanford site near Richland, Washington, stores approximately 53 million gallons of chemically hazardous and radioactive wastes in 177 underground tanks, 149 single-shell tanks (SSTs) and 28 double-shell tanks (DSTs). The storage of waste in the SSTs poses greater environmental risks than storage of wastes in DSTs, which are newer and have a second shell to mitigate leakage. DOE has removed pumpable liquids from the SSTs to reduce the threat of leakage during waste storage. However, the 28 DSTs have inadequate capacity to receive all of the SST wastes. When waste is withdrawn from the DSTs for treatment in the Waste Treatment Plant and Immobilization Plant (WTP), additional SST wastes will be retrieved and transferred to DSTs. Until WTP commences radioactive waste operations, the rate of SST retrievals will be constrained by the availability of DST space. This situation is illustrated in Figure ES-1.

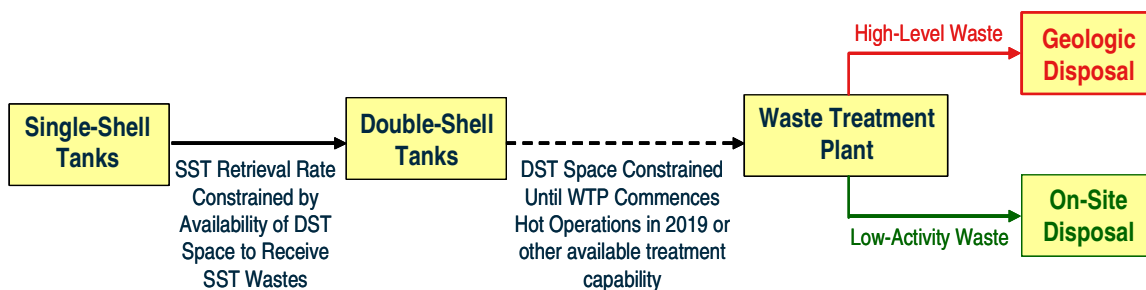


Figure ES-1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rate

Most of the Hanford tank wastes resulted from recovery of plutonium for defense purposes from spent nuclear fuel. The radioactive material content in the Hanford tanks, approximately 195 million curies including fission product daughter radionuclides, makes up only a small percentage of the tank waste dry mass. Most of the tank waste dry mass consists of chemicals added to the wastes during reprocessing or other Hanford operations, and for corrosion control. As a result, DOE has long planned to separate the chemical materials from the radioactive materials, to the extent practical, in order to minimize the mass of waste it disposes of in a geological repository. The WTP Pretreatment Facility is designed to produce a high-level waste (HLW) feed stream that contains over 95 percent of the radioactivity and a LAW feed stream that contains over 90 percent of the chemical dry waste mass (see Figure ES-2).

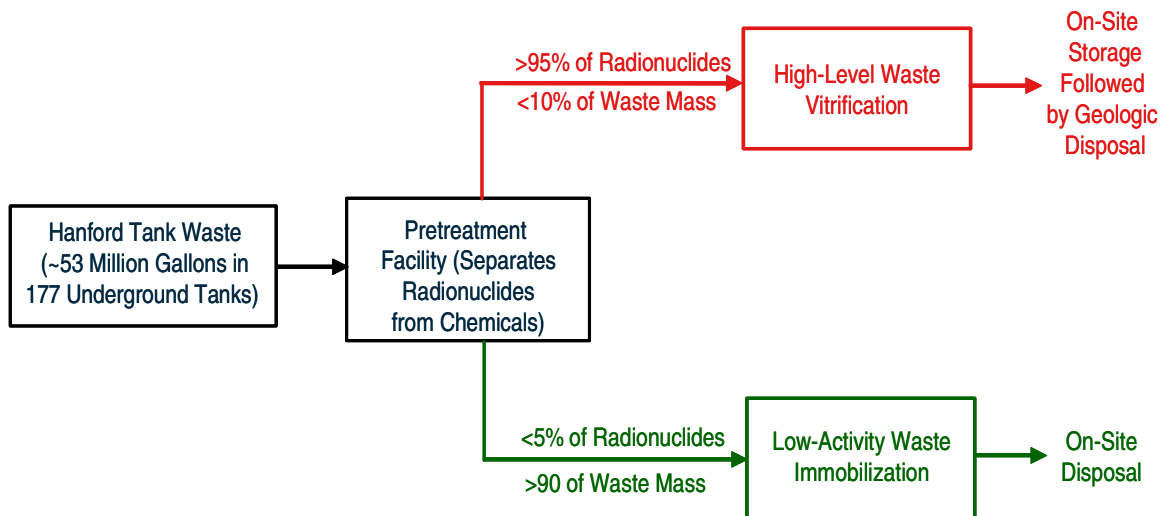


Figure ES-2. Simplified Hanford Tank Waste Treatment and Immobilization Flow Diagram

The pretreated HLW feed will be vitrified (incorporated into glass) and stored on-site until disposed of in geological repository. The pretreated LAW feed will also be immobilized but it will be disposed of on-site. The LAW fraction that is immobilized by the WTP LAW Facility will be vitrified. The LAW fraction that is immobilized by a supplemental LAW immobilization technology could be vitrified or immobilized using alternative processes as discussed in this report.

The WTP HLW Facility is designed to vitrify all of the pretreated HLW feed over a 23- to 35-year period. Based on the WTP commencing hot (radioactive) operations in 2019, HLW immobilization would be complete between 2042 and 2054. DOE currently estimates that it will produce between 10,000 and 14,000 HLW canisters depending upon the effectiveness of its initiatives to increase waste loading in the glass. At approximately 3.2 metric tons (MT) of glass per canister, that production translates into approximately 32,000 to 44,800 MT of HLW glass.

DOE has planned, since the inception of the WTP Project in the mid-1990s, to add additional LAW immobilization capacity. The current WTP configuration provides capacity to vitrify approximately 50 percent of the projected amount of LAW to be treated over the projected operating period. For that reason, in 2002, DOE, Washington State Department of Ecology, and U.S. Environmental Protection Agency undertook an evaluation of a wide range of potential LAW immobilization technologies as potential options to building a second WTP LAW facility. The agencies ultimately identified a second LAW facility, Bulk Vitrification (BV), Cast Stone (CS), and Steam Reforming (SR) facilities as the most viable options. The Hanford Tank Farm Contractor issued contracts to technology vendors to develop waste forms based on each of these technology options for DOE's consideration and to develop pre-conceptual designs to implement the supplemental immobilization technologies. Based on its evaluations of the vendors' submissions, DOE elected to proceed with BV testing at the Hanford site, SR testing at its Idaho site, and CS (grout) testing at its Savannah River Site.

DOE has not yet selected a definitive immobilization process to supplement its Hanford LAW Facility. DOE will make that decision in accordance with its project management orders and the

National Environmental Policy Act of 1969 (NEPA), pursuant to the *Tank Closure and Waste Management Environmental Impact Statement (TC & WM EIS)*¹. Currently, a draft environmental impact statement (EIS) is planned to be completed in 2009 for public comment. Subsequently, a performance assessment of the planned disposal facility for treated LAW will provide important input to the necessary characteristics of the treated waste forms for disposal.

REVIEW SCOPE

DOE has the ongoing task of evaluating and selecting options that improve the effectiveness and efficiency of accomplishing the tank waste treatment mission at Hanford, while considering the full life cycle of the planned tank farm and WTP operations. This review focused on three primary areas:

- Review the systems plans for Alternative Supplemental Treatment of LAW at Hanford, from retrieval to final disposition.
- Review the ORP path forward for LAW disposition, including the option and approaches for initiating treatment of LAW prior to commencing full WTP operations (“Early LAW”), and further testing of BV.
- Provide a preliminary qualitative evaluation of the issues and benefits associated with the potential installation of a third LAW melter, based on the available information.

The review also included consideration of the major uncertainties that may impact completion of the waste treatment mission.

UNCERTAINTIES THAT IMPACT PROGRAM NEEDS, SCHEDULE, AND COST

Currently, the construction of LAW and analytical laboratory facilities at WTP are scheduled, by contract, for completion in 2012; and the pretreatment and HLW vitrification facilities and balance of the plant are scheduled for completion in 2017, with radioactive waste processing scheduled to begin in 2019. After initiation of radioactive waste processing in the HLW vitrification facility, an estimated 23 to 35 years will be required to complete HLW vitrification if HLW vitrification is the limiting factor to mission completion. However, the availability of timely and sufficient pretreatment capability and sufficient LAW processing capacity may, in fact, be the limiting factor to mission completion, thereby extending the mission duration by several years or decades, if balanced processing capability is not available.

¹ 71 FR 5655, “Notice of Intent To Prepare the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, WA,” *Federal Register*, February 2, 2006.

There are several administrative, programmatic, and technical uncertainties that can impact the mission duration and completion dates. They include the following:

1. *Program planning and priorities prior to and after beginning of initiation of radioactive waste processing.* Tank farm infrastructure upgrades, evaporator maintenance, and waste retrieval operations from HLW tanks must be implemented on a schedule that supports timely start up of overall WTP operations in 2019. After initiation of full WTP waste processing, adequate planning and priority is needed for waste retrieval infrastructure upgrades and operations, additional storage capacity for vitrified HLW canisters prior to shipment to a national geologic repository for disposal, and WTP facility upgrades.
2. *Regulatory approval of planned operations and treated waste disposal.* Additional regulatory approvals or permits are required for WTP operations; disposal of vitrified LAW on-site at Hanford in the Integrated Disposal Facility (IDF); acceptance of vitrified HLW for disposal at a national geologic repository; and disposal of TRU retrieved from ORP tank farms at the Waste Isolation Pilot Plant (WIPP; Carlsbad, New Mexico).
3. *Planning and implementation for timely availability of supplemental LAW treatment capacity, if needed.* Considerable uncertainty exists about the schedule and capacity needed for supplemental LAW treatment and the technology choices that should be used to provide supplemental LAW treatment. Notwithstanding these uncertainties, failure to provide resources for adequate design and planning, along with timely implementation of supplemental LAW treatment capacity can result in schedule extension of the WTP mission. Insufficient LAW capacity would result in LAW treatment becoming the rate limiting process for overall mission completion and potentially could extend overall mission completion.
4. *Administrative plant outages in response to accidents and plant upsets.* Operating outages at the WTP and tank farms, in response to either accidents or plant upsets, currently are not explicitly included in systems modeling and schedule planning; instead, a contract-mandated WTP availability (70 percent) is uniformly imposed. Benchmarking of the 70 percent plant availability is not presently available and the realism of this expectation is uncertain.

The technical uncertainties that can result in significant delays in either the beginning of full WTP waste processing or completion of the mission include the following:

1. *The amount of sodium to be processed as part of LAW treatment.* The amount of sodium to be processed as part of LAW treatment directly impacts the overall amount of vitrified LAW that will be produced, and the time required for LAW mission completion based on available LAW treatment capacity. This will occur because sodium limits the overall waste loading in the vitrification process. Sodium is part of the waste stream because sodium hydroxide was used in prior processing and for corrosion control. In addition, sodium hydroxide is used as part of HLW pretreatment process. The goal of sodium hydroxide addition is to keep the free hydroxide ion content above the minimum necessary to control corrosion in the tank farms and to prevent aluminum precipitation during WTP processing. The amount of sodium currently in inventory within the tank farms is known with reasonable certainty although there is significant uncertainty in the amount of free hydroxide ion in the tanks. The amount of sodium that will result from HLW pretreatment is more uncertain, in part because sodium additions are derived from a

sodium-hydroxide ion balance, which results in a higher uncertainty in the overall amount of sodium to be processed. The initial estimate for overall sodium requiring treatment as LAW was 60,000 MT. Recent estimates range up to 90,000 MT of sodium, with considerable uncertainty in the underlying calculations. On the basis of a 35-year mission, and contractual facility performance requirements, the current LAW treatment capacity is only about 40,000 MT sodium.

2. *Tank farm waste retrieval rates.* Tank waste retrieval scenarios have been modeled and the resulting simulations were used to estimate retrieval rates, considering the current tank farm configuration and a limited set of infrastructure improvements. Several scenarios indicate the potential for tank farm waste retrievals, especially waste retrieval from tanks presumed to have leaked (or are more likely to leak), becoming the rate limiting process for overall WTP mission completion.
3. *Glass composition and waste loading rate improvements.* Improvements in the waste loading, especially for aluminum, in HLW glass can reduce the amount of HLW requiring pretreatment and the required LAW treatment capacity. Improvements in the waste loading, especially for sodium, in the LAW glass also can reduce the required LAW treatment capacity. Scenarios evaluated to date have been based on a LAW waste loading model that projects lower waste loading in LAW glass than has been demonstrated through recent studies. Formulations that allow higher waste loading are being evaluated and once fully developed may be adopted by WTP as a design or operational basis. Mission scenarios that include the recently demonstrated higher waste loading as input are being developed.
4. *WTP HLW and LAW glass production rates.* The production rates for both the overall HLW and the LAW vitrification systems are subject to uncertainty from various sources, including the assumed processing plant availability. There also appears to be potential to increase the glass production rate capacity for the two planned LAW melters by modifying the WTP LAW facility now to accommodate enhanced melters in the future.
5. *WTP pretreatment system capacity.* Prior reviews have identified several concerns that may significantly impact the overall performance of the WTP pretreatment system. These concerns are being actively pursued through a series of issue response plans. The results of these evaluations and technology maturation will require approximately 2 years. In addition, any potential temporary shut-down of the WTP pretreatment system, under the current configuration, represents a single-point failure mode that would result in the shutdown of the entire WTP facility. Supplemental pretreatment capability could alleviate this single-point failure mode.

TIMELINE

The current schedule for several key potential activities and events plays a major role in the evaluation and prioritization of potential alternatives. Figure ES-3 provides a summary of this information.

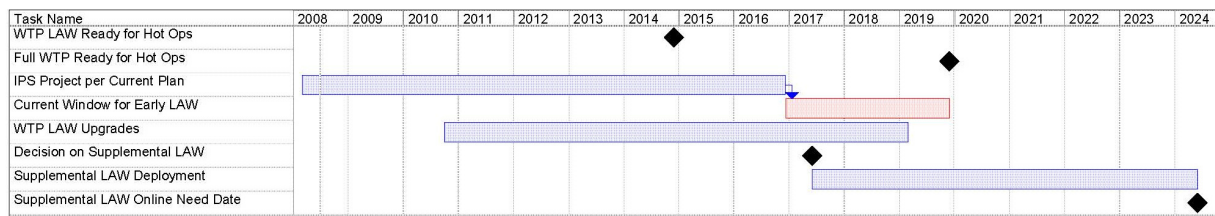


Figure ES-3. Timeline: Potential Activities Based on Current Schedule Information

The following are key factors:

- Early LAW.** The current schedule for completion of the WTP LAW and supporting facilities (BOF and LAB) would support early treatment of LAW beginning in 2014. However, this support requires the provision of an interim pretreatment capability and a means for the disposition of secondary wastes. The current baseline plan is to deploy an Interim Pretreatment System (IPS); however, the present schedule for development, design, and deployment does not support a 2014 start for Early LAW (which brings IPS online in about 2016), reducing the potential return on the IPS investment (and other required investments) and the benefits associated with Early LAW. Any delay in the IPS completion would further exacerbate this situation. However, IPS can provide additional pretreatment capacity beyond Early LAW, if needed.
- LAW upgrades.** WTP LAW treatment capacity could be significantly increased through upgrades to the LAW facility, including the addition of a third melter line, or increasing the throughput capability of each melter line. However, implementation of these upgrades prior to hot operations would preclude the Early LAW option. Performing these modifications after the start of hot operations would be a less attractive option because of the need for significant plant outages, based on presently available analyses. The potential for such upgrades to reduce or eliminate the need for supplemental LAW treatment facilities depends on the sodium inventory and the acceptable mission duration.
- Supplemental LAW treatment.** As currently designed, the WTP LAW facility determines the overall mission duration unless additional LAW treatment capacity is added. Based on the projected need date of 2024 and a 7 year deployment time for this additional capacity, a selection decision is needed from the possible supplemental treatment alternatives by ~2017. The current uncertainties in sodium inventory and in the requirements for additional LAW treatment capacity need to be reduced before decisions are made on supplemental treatment technologies. Technical options to

provide supplemental LAW treatment capacity include BV or a second LAW facility to produce vitrified LAW. Other approaches may require changes to ORP policy.²

COMPARATIVE SCHEDULE AND COST ANALYSIS OF SELECTED SCENARIOS

A comparative schedule and cost analysis was carried out for four broad scenarios (or courses of action) to address LAW treatment needs. Each scenario was evaluated under assumptions of treating 60,000 and 90,000 MT sodium. In addition, a minimum mission duration of 30 years was assumed to facilitate comparison with the present RPP plan; however, shorter mission durations may be possible with improvements in efficiency to waste retrievals and operations. The scenarios, and variants, evaluated are outlined below:

- 1a. WTP only – implementation only of the WTP LAW vitrification facility currently under construction (no supplemental LAW treatment).
- 1b. WTP with Early LAW – Scenario 1a, above, with the addition of IPS and starting LAW processing at the WTP LAW vitrification facility 5 years prior to the start up of the WTP pretreatment and HLW vitrification facilities.
- 2a. Present RPP Plan – implementation of the WTP LAW vitrification facility currently under construction, IPS, demonstration BV and supplemental treatment (BV).
- 2b. Present RPP Plan with Early LAW (mission completion in 2046 for 60,000 MT Na) – Scenario 2a, above, with the addition of IPS and starting LAW processing at the WTP LAW vitrification facility 5 years prior to the start up of the WTP pretreatment and HLW vitrification facilities. Five years of Early LAW operation reduces the overall WTP mission duration by 2.5 years because only approximately half the LAW is planned to be processed by the WTP LAW vitrification facility.
- 2c. Present RPP Plan with Early LAW (mission completion in 2049 for 60,000 MT Na) – Scenario 2a, above, with the addition of IPS and starting LAW processing at the WTP LAW vitrification facility prior to the start up of the WTP pretreatment and HLW vitrification facilities and resulting in negligible impact on the WTP mission completion date.
- 3a. Enhanced WTP (3rd LAW melter) – implementation of the WTP LAW vitrification facility currently under construction enhanced through the addition of a third melter.
- 3b. Enhanced WTP (two 22.5 MT/day melters) – implementation of the WTP LAW vitrification facility currently under construction enhanced through increasing the capacity of the two planned melters.
- 4a. Second LAW – implementation of the WTP LAW vitrification facility currently under construction and implementation of a second LAW vitrification facility with LAW processing at the second LAW facility starting in 2024.
- 4b. Second LAW with Early LAW – Scenario 4a, above, with the addition of IPS and starting LAW processing at the WTP LAW vitrification facility 5 years prior to the start up of the WTP pretreatment and HLW vitrification facilities. Five years of

² As previously noted, other options (Cast Stone and Steam Reforming) are potentially viable, going through technical demonstration at other sites, and included in the EIS deliberations.

Early LAW operation reduces the overall WTP mission duration by 2.5 years because only approximately half the LAW is planned to be processed by the WTP LAW vitrification facility.

- 4c. Enhanced Second LAW – Scenario 4a, above, with the capacity of the second LAW vitrification facility enhanced to achieve completion of the WTP mission by 2049 (e.g., through either use of enhanced melters and/or a third melter).

WTP mission duration, completion date and life-cycles present worth were modeled, including cost uncertainty assessment. A summary of the results from this analysis is provided in Table ES-1. This analysis indicates the following:

1. A second LAW vitrification facility (Second LAW and Enhanced Second LAW) would provide the most favorable present worth while making possible attainment of the 2049 current system plan mission completion date for the full range of potential sodium quantities assumed to be treated. This result is possible because of the flexibility in sizing the capacity of a second LAW vitrification facility and that the selection and capacity sizing decision would not be required until 2017, allowing time to reduce key program uncertainties.
2. Inclusion of Early LAW with any of the base scenarios (WTP Only, Present RPP system Plan, or Second LAW) results in an insignificant reduction in life-cycle present worth. However, non-financial benefits derived from Early LAW also warrant consideration.
3. If schedule flexibility exists, enhancements to the present LAW facility would result in a six-year mission extension beyond the current system plan completion date of 2049 and provide a favorable present worth, under the assumption of 60,000 MT Na.
4. Each of the scenarios requires implementation of a different sequence of capital and operating expenses for either facility enhancements or new facilities, and therefore has different cost-time profiles, which are contained in the present worth analyses.

Table ES-1. Summary Level Comparison of Results From Evaluation of Four Scenarios and Associated Variants.

Scenario	60K MT Na Duration (years)	60K MT Na Present Worth (\$ B)	90K MT Na Duration (years)	90K MT Na Present Worth (\$ B)	“New” Nuclear Facilities	Intangibles
1a. WTP Only	54	29.3	74	34	None	Inconsistent with present stakeholder understandings
1b. WTP only w/ELAW	54	29.3	74	33.8	IPS, Secondary Waste	Inconsistent with present stakeholder understandings; ELAW provides: demonstrated progress in vitrification, DST space, extra SST retrievals, staggered facility startup
2a. Present RPP Plan	30	27.1	36	29.8	IPS, Two BV	Familiar to stakeholders
2b. Present RPP Plan w/ELAW [2046]	32	27.0	38	29.7	IPS, Two BV, Secondary Waste	Familiar to stakeholders; BV provides scalable ST ELAW provides: demonstrated progress in vitrification, DST space, extra SST retrievals, staggered facility startup
2c. Present RPP Plan w/ELAW [2049]	35	28.2	41	30.8	IPS, Two BV, Secondary Waste	Familiar to stakeholders; BV provides scalable ST ELAW provides: demonstrated progress in vitrification, DST space, extra SST retrievals, staggered facility startup
3a. Enhanced WTP [3 rd Melter]	36	25.9	51	31.2	None	Precludes ELAW Proven melter design and technology
3b. Enhanced WTP [(2) 22.5 MT/d melters]	36	26.1	51	31.5	None	Precludes ELAW; Proven melter technology
4a. Second LAW	30	25.0	35	27.5	2 nd LAW	Builds on LAW experience to reduce technology, cost, and schedule risk; Provides scalable ST
4b. Second LAW w/ELAW	32	24.9	37	27.8	2 nd LAW, IPS, Secondary Waste	Builds on LAW experience to reduce technology, cost, and schedule risk; Provides scalable ST ELAW provides: demonstrated progress in vitrification, DST space, extra SST retrievals, staggered facility startup
4c. Enhanced Second LAW	30	26.4	30	26.7	2 nd LAW	Builds on LAW experience to reduce technology, cost, and schedule risk; Provides scalable ST 2 nd LAW sized to complete 30 yr mission

Abbreviations: BV – bulk vitrification; IPS – interim pretreatment system; ST – supplemental treatment; ELAW – Early LAW; DST – double shell tanks; SST – single shell tanks

CONCLUSIONS AND RECOMMENDED PRIORITIES

This evaluation indicates that a decision on how to proceed, including the technical approach, with providing supplemental LAW treatment capacity is not needed until 2017. The amount of supplemental LAW treatment capacity needed is highly uncertain, and dependent on several program aspects that currently are highly uncertain, including the amount of sodium to be treated with LAW and the rate of waste retrievals from single shell tanks. Reducing key program uncertainties requires urgent attention to be prepared for the proposed 2017 decision schedule. A second LAW vitrification facility would provide extensive flexibility in the additional treatment capacity to be constructed, depending on the number and capacity of melters and supporting systems included, and appears most favorable from a financial perspective. A second LAW facility would also permit attainment of WTP mission completion by 2049 for the currently considered full potential range of sodium requiring treatment (60,000 to 90,000 MT Na). Enhancements to the present LAW facility would also provide a potentially viable option under the assumption of 60,000 MT Na, if there is flexibility to go to a 36-year WTP mission.

For the ORP path forward to address the disposition of LAW, the review team recommends the following list of priorities. These priorities are based on the team's current understanding of schedule and technical constraints. As indicated above, there are many uncertainties that could impact the overall needs and progress of the program; therefore, periodic review of priorities should be considered as new information becomes available.

High Priority

1. **Complete WTP by 2019; ensure timely feed delivery.** Completing WTP construction and initiating waste processing operations by 2019 should be the program's highest priority. Waste retrieval and transfer limitations could potentially extend mission duration. Currently, we believe that infrastructure upgrades and waste retrieval system improvements essential for providing feed to the WTP have too low visibility and priority. We recommend establishing a separate project comprised of the elements that are essential for meeting feed delivery expectations. In addition, waste retrievals from the single shell tanks required by the TPA should be used as a foundation for improving waste retrieval efficiency. *This priority is urgent and requires ongoing attention.*
2. **Develop and implement a sodium management strategy.** Reducing the quantity of sodium in LAW to be vitrified, and the associated uncertainty in this quantity, is the most important element in determining the duration, need for additional LAW treatment capacity, and cost of the mission. Sodium is the primary constituent in vitrified LAW that limits waste loading and thereby determines the quantity of vitrified LAW to be produced; other constituents present in the waste, such as sulfur, could further limit waste loading in vitrified LAW. Sodium, which is already present in the waste, is also added during pretreatment of HLW as part of aluminum and chromium extraction from HLW to

reduce the vitrified HLW production.³ Uncertainty in both the waste composition currently stored in the HLW tanks and the amount of sodium required to be added during HLW pretreatment render highly uncertain the estimate of the actual sodium quantity to be treated.⁴ The current estimates of sodium quantity appear to be biased (high) as a result of limitations in thermodynamic models, uncertainty in the amount of free hydroxide ion in the current inventory, and margins used for sizing process equipment.⁵ Several potential process modifications could also reduce the amount of sodium to be treated and the vitrification capacity required to treat the final amount of sodium. Resolution is needed prior to 2017 for the approaches to optimize sodium management, along with the amount and approach to additional LAW treatment capacity, for timely construction of additional processing facilities, if needed. Some options could have long development and demonstration lead times or be limited or eliminated by progression of WTP construction. Development and implementation of an integrated strategy to address sodium management and future LAW treatment capacity needs is in its infancy and urgently needed. The scope of the sodium management plan should include quantification of the uncertainty and bias in current sodium estimates; uncertainty reduction strategies and tracking of uncertainty reductions, improved thermodynamic and kinetic models for key process steps, especially aluminate solution stability, and evaluation, including demonstration when promising, of process modifications that reduce the amount of sodium to be treated and the needed LAW vitrification capacity. *This priority is urgent.*

3. **Improve integrated system modeling capability.** A complete, consistent and integrated model of tank farm, retrievals, operations, and WTP system performance is essential for program management, providing a basis for schedules, cost estimates, and evaluation of “what if?” scenarios. The resulting model should be an accurate reflection of the current understanding of the entire system and include uncertainty evaluation, formal optimization, and updating strategies. The user interface should facilitate rapid modification and documentation of model run assumptions and parameters. Management and implementation strategies should be modified to facilitate much more extensive and near real-time use of the model as a system planning and evaluation tool. An independent review, with appropriate expertise, that is specifically focused on the model implementation and use is recommended. *This priority requires ongoing attention.*

³ The program considers the disposition of vitrified HLW in an off-site national geologic repository to be far more expensive than on-site disposal of vitrified LAW and therefore seeks to minimize the quantity of vitrified HLW produced.

⁴ Uncertainties in waste inventory with respect to sulfur, aluminum speciation, chromium, sodium and other constituents impact the uncertainty in the amount of sodium to be treated. The amount of sodium hydroxide to be added during pretreatment under the current process plan also is highly uncertain.

⁵ Bias is introduced into estimates when a safety margin, or “conservativeness” is applied (appropriately) for specific design purposes, but then the resulting estimates are used for other purposes (e.g., program planning) without recognition of the inherent bias or uncertainty in the estimates.

Medium Priority

- 4. Reduce uncertainty in supplemental treatment capacity needs (requires Priorities 2 and 3, above).** Components to reducing uncertainty in the amount of sodium to be processed should include evaluation of potential flowsheet modifications to reduce sodium additions during processing, laboratory and bench-scale testing for process and thermodynamic and kinetic model development, and engineering-scale process demonstration. Pretreatment engineering-scale platform (PEP) Phase II testing, employing a wider range of simulants and process conditions, will be important to reducing uncertainty related to WTP pretreatment operation. Additionally, strategies that further reduce the needed LAW vitrification capacity, beyond sodium use reduction, should be evaluated, including use of fractional crystallization to separate sodium, sulfate (to improve sodium loading in LAW glass), and reduce ⁹⁹Tc in LAW; and development of an improved performance assessment for the on-site disposal of treated LAW. The impact of these strategies on associated waste forms needs to be included as part of the evaluation process. Support should also continue for improved glass formulations that allow increased waste loadings for both HLW and LAW. *This priority, after implementation of Priority 2, is urgent and requires ongoing attention.*
- 5. Evaluate WTP LAW upgrades that provide for future capacity enhancement.** Preliminary evaluation suggests the capacity of the WTP LAW facility may be significantly increased in the future if physical modifications to balance of plant facilities (such as electrical supply or cooling capacity) are made prior to construction completion. Specifically, providing increased system capacity now that would allow upgrades in individual melter capacity from 15 MT glass per day to 22.5 MT glass per day with either two or three melters during planned melter replacements may be practical, financially attractive, and not delay overall WTP construction completion. However, WTP LAW upgrades may put completion of WTP LAW on the critical path for overall WTP construction completion. Evaluation of these options would also provide insights into potential design improvements for a second LAW facility, if selected. However, for modifications to the LAW facility currently under construction, the impact on the current skilled labor employed at WTP construction and by vendors also should be considered. The additional capital cost of LAW upgrades to allow future installation of two enhanced melters is approximately \$930 million over the interval of 2010 to 2019. *A decision of whether or not to proceed with WTP LAW upgrades is urgent, to avoid extension of WTP completion, if this option is selected.*
- 6. Enhance support for focused technology demonstration.** The EM-20 and field technology demonstration programs provide early support for technology maturation that must be completed prior to technology adoption as part of program plans. Insufficient support for this program prevents timely availability of some promising approaches (because of insufficient remaining lead time for needed maturation) and increases programmatic risk for other approaches due to only limited testing. Sufficient support should be made available for approaches that improve waste retrieval efficiency, implement the sodium and aluminum management strategy, improve system modeling capabilities, and reduce the need for supplemental treatment capacity (Priorities 1, 2, 4, and 5 above). Support is also needed for evaluation of cementitious and other low-

temperature treatments for secondary wastes. The current program clearly has benefitted from earlier technology demonstration investments, such as in rotary microfiltration, waste retrieval technology, fractional crystallization, waste-loading improvements, and melter capacity enhancements. *This priority is an ongoing need.*

7. **Refine TRU strategy.** Improved coordination will be needed between the ORP and WIPP programs to establish the schedule, define requirements, and obtain needed approvals for disposition of TRU tank waste at WIPP. Currently, disposal of TRU waste from ORP is not part of the TRU waste management plan for WIPP. *This priority requires attention to ensure schedule compatibility between ORP and WIPP plans.*
8. **Planning for Early LAW and supporting systems.** The primary benefits of Early LAW are early demonstrated progress in LAW treatment (assuming operations from 2014 to 2019), freeing up DST space, and retrieval of 5 to 10 additional SSTs; providing an opportunity to better understand LAW performance and identify improvements in a timely manner to support supplemental treatment decision making and planning for initial melter replacement; and staggering the start up, and associated staffing and training, of the major WTP facilities. (The planned rapid change in staff requirements and training associated with WTP start up is a concern and additional options to alleviate this potential bottleneck should be explored.)

Total additional cost for Early LAW is estimated at \$300 million for capital expenses and \$1 billion for operating expenses from fiscal year (FY) 2009 through 2019. Results of this evaluation indicate that the reduction in life-cycle costs is not sufficient alone to justify proceeding with Early LAW, but the decision also should consider the non-financial benefits indicated.

Early operation of LAW requires additional WTP modifications, interim pretreatment, and a strategy for interim management of secondary waste. Estimates provided to the team indicate that interim pretreatment requires 4 to 7 years for new facility construction, and development of a secondary waste management strategy is in very early stages. Thus, the current schedule for required system functionality to support early LAW may not support a 2014 start and may not provide a sufficient operating window to be justified. Early LAW also would preclude WTP LAW upgrades (Priority 5, above). This analysis is based on currently available information and assumptions and did not include review of the new Tank Operations Contractor (TOC) proposal. The relative benefit and priority of Early LAW should be re-evaluated if either WTP LAW upgrades (Priority 5, above) are found to be impractical based on more detailed evaluation; WTP construction completion is delayed beyond 2019; or the schedule and costs associated with supporting systems necessary for Early LAW are substantially reduced. *A decision of whether or not to proceed with Early LAW is urgent.*

Low Priority

9. **Planning and development for BV.** BV is an “in-container” vitrification process, where the container in which the waste is vitrified is also used for final disposal. Considerable progress has been made in the development of BV technology through extensive research and development testing. However, the testing of this technology and the design of a

demonstration system support fewer advantages of this technology over other potential supplemental treatment alternatives than previously thought. In view of the need date for supplemental treatment down-selection (about 2017), the current uncertainties in sodium inventory, and the requirements for additional LAW treatment capacity—coupled with the advanced level of our understanding of this technology—further development work on BV should not receive a high priority. Testing results have indicated that waste loading to avoid phase separation of sulfur and the distribution of technetium within the treated waste and the off-gas treatment system remain as critical issues. *Further testing of bulk vitrification is not urgent.*

EXTERNAL TECHNICAL REVIEW OF SYSTEM PLANNING FOR LOW ACTIVITY WASTE TREATMENT AT HANFORD

1.0 BACKGROUND⁶

The DOE Hanford site near Richland, Washington, stores approximately 53 million gallons of chemically hazardous and radioactive wastes in 177 underground tanks, 149 SSTs and 28 DSTs. A concise overview of the storage, retrieval, and plans for treatment of these wastes has been provided elsewhere (see DOE-ORP 2007) and is the basis for this section of the report. The storage of waste in the SSTs poses greater environmental risks than storage of wastes in DSTs, which are newer and have a second shell to mitigate leakage. Sixty-seven of the SSTs previously leaked as much as 1 million gallons of tank waste into the soil surrounding the Hanford tanks; this leakage has increased risk to the Hanford area groundwater and the Columbia River. As a result, DOE has removed pumpable liquids from the SSTs to mitigate the threat of additional leakage during waste storage. Leakage risks increase and are carefully managed when DOE adds liquids to SSTs to retrieve wastes from those tanks.

The 28 DSTs have inadequate capacity to receive all of the SST wastes. Additional DST space will be created as waste is withdrawn from the DSTs for treatment in the Waste Treatment Plant (WTP), which will enable additional SST wastes to be retrieved. DOE estimates that it can achieve base on recent experience, on average, one SST retrieval each year (primarily sludge tanks from C-Farm) between now and the time that the WTP is presently estimated to commence hot operations in 2019. Until that time, the rate of SST retrievals will continue to be constrained by the availability of DST space. This situation is illustrated in Figure 1.

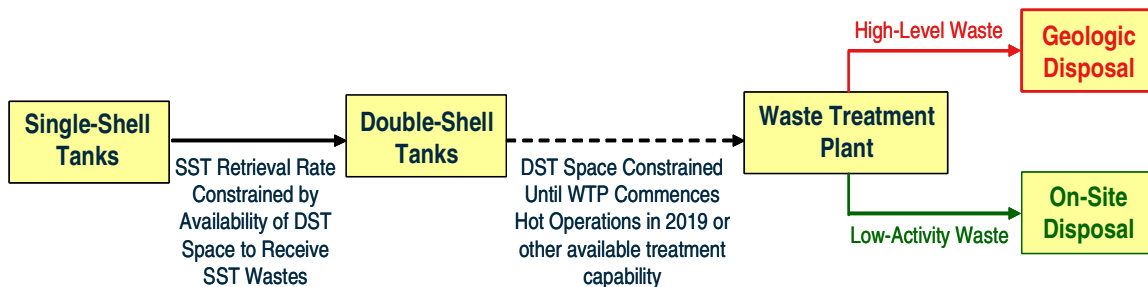


Figure 1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rate

⁶ This section is in large part derived from the LAW Business Case Evaluation (DOE-ORP 2007).

Most of the Hanford tank wastes resulted from spent nuclear fuel reprocessing (i.e., recovery of plutonium for defense purposes from spent nuclear fuel). The radioactive material content in the Hanford tanks, approximately 195 million curies including fission product daughter radionuclides, comprises only a small percentage of the tank waste dry mass. Most of the dry tank waste mass consists of chemicals added to the wastes during reprocessing, during other Hanford operations, and for corrosion control. As a result, DOE has long planned to separate the chemical materials from the radioactive materials to the extent practical in order to minimize the mass of waste it disposes of in the Yucca Mountain HLW repository. The WTP PT Facility is designed to produce a HLW feed stream that contains more than 95 percent of the radioactivity and a LAW feed stream that contains over 90 percent of the chemical dry waste mass (see Figure 2).

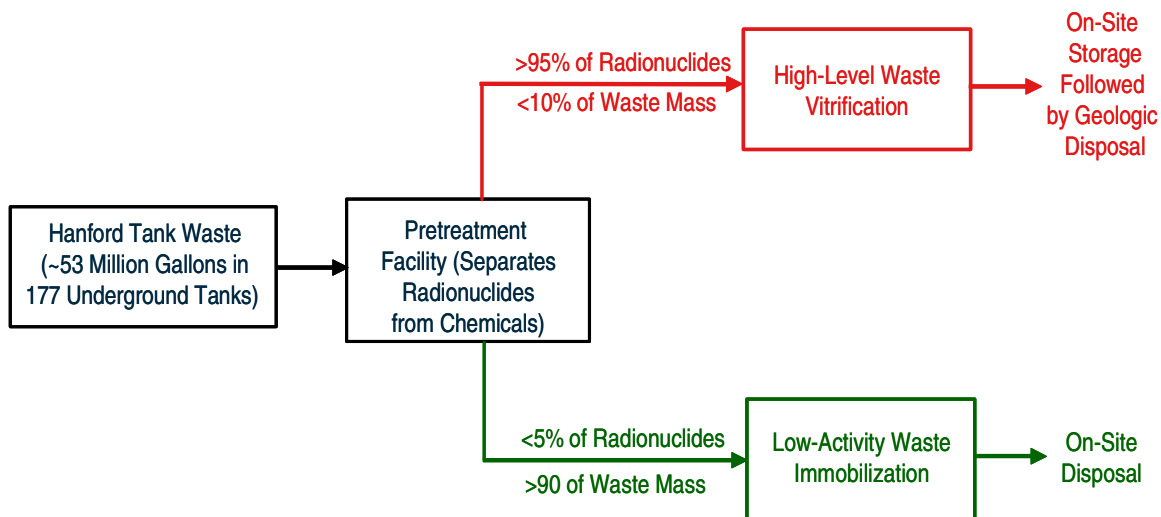


Figure 2. Simplified Hanford Tank Waste Treatment and Immobilization Flow Diagram

The pretreated HLW feed will be vitrified (transformed into glass) and stored on site until it can be disposed of in the proposed spent nuclear fuel and HLW repository at Yucca Mountain, Nevada. The pretreated LAW feed will also be immobilized, but it will be disposed of on site. The LAW fraction that is immobilized by the WTP LAW Facility will be vitrified. The LAW fraction that is immobilized by a supplemental LAW immobilization technology, if any, could be vitrified or immobilized using alternative processes, as discussed in this report.

The WTP HLW Facility is designed to vitrify all of the pretreated HLW feed during a 23- to 35-year period. Based on the WTP commencing hot (radioactive) operations in 2019 and the currently projected 27 to 35 year HLW pretreatment and immobilization mission duration, HLW immobilization would be complete between 2042 and 2054. DOE currently estimates that it will produce between 10,000 and 14,000 HLW canisters depending upon the effectiveness of its initiatives to increase waste loading in the glass. At approximately 3.2 MT of glass per canister, that production translates into approximately 32,000 to 44,800 MT of HLW glass. For comparison, if DOE vitrified all Hanford LAW in the WTP LAW Vitrification Facility, it would produce approximately 400,000 MT of LAW glass; i.e., there would be approximately 10 times as much LAW glass as HLW glass.

DOE has planned, since the inception of the WTP Project in the mid-1990s, to add additional LAW immobilization capacity. For that reason, in 2002, DOE, Washington State Department of

Ecology, and U.S. Environmental Protection Agency undertook an evaluation of a wide range of potential LAW immobilization technologies as potential options to building a second WTP LAW facility. The agencies ultimately identified a second LAW facility, BV, CS, and SR facilities as the most viable options for supplementing the WTP LAW Vitrification Facility. The Hanford Tank Farm Contractor issued contracts to the BV, CS, and SR facility technology vendors to develop waste forms for DOE's consideration and to develop pre-conceptual designs to implement the supplemental immobilization technologies. Based on its evaluations of the vendors' submissions, DOE elected to proceed with BV testing at the Hanford site, SR testing at its Idaho site, and CS (grout) testing at its Savannah River Site.

DOE has not yet selected a process to supplement its Hanford LAW Facility. DOE will make that decision in accordance with its project management orders and the *National Environmental Policy Act of 1969* (NEPA), pursuant to the *Tank Closure and Waste Management Environmental Impact Statement* (TC & WM EIS)⁷.

2.0 SCOPE OF THE REVIEW

This review focused on three primary areas:

- Review the systems plans for Alternative Supplemental Treatment of LAW at Hanford, from retrieval to final disposition
- Review the Office of River Protection (ORP) path forward for LAW disposition
- Provide a preliminary qualitative evaluation of the issues and benefits associated with the potential installation of a 3rd LAW melter, based on the available information.

3.0 TEAM MEMBERSHIP

The team was comprised of five independent experts whose credentials and experience align with the specific lines of inquiry (LOI) listed below and who collectively provided sufficiently broad capability and flexibility to address the full range of issues that are the subject of this review. The team's technical expertise includes design, engineering, and management of chemical processing and radioactive waste management systems. Members of the team were Dr. David Gallay (LMI), Dr. David Kosson (Vanderbilt University), Dr. Ian Pegg (Catholic University), Dr. Ray Wymer (retired from Oak Ridge National Laboratory (ORNL)), and Dr. Steven Krahn (DOE-EM-21). Appendix A provides brief biographies for each team member. The experts are free of any conflicts of interests with Bechtel or CH2M Hill Hanford Group.

4.0 LINES OF INQUIRY

An integrated program strategy and systems approach ensures that all operations and interfaces, risks, and alternatives are evaluated to ensure that adequate throughput, schedule, and other overall mission requirements are met to achieve mission objectives. "Adequate" considers

⁷ 71 FR 5655, "Notice of Intent To Prepare the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, WA," *Federal Register*, February 2, 2006.

maturity of each aspect, considering the current point in the mission and ability to avoid delays in the overall mission schedule.

The following were the primary LOI for the review:

ORP Strategy and Systems Approach

1. Is there an adequate overarching strategy (master plan or schedule) to integrate all systems and operations under consideration that will be necessary for processing high-level tank waste at Hanford?
2. Is the degree of development and planning adequate to meet the schedule for implementation?
3. What aspects of a systems approach are in place, and which aspects are missing?
4. Is the overall mass balance and throughput consistent with mission requirements, and are mass and energy balances consistent between operations and interfaces for all options and combinations under consideration?

LAW Processing

5. Are LAW processing requirements projected for all tank waste process options and combinations under consideration including additional sodium separations, Early LAW scenario, 3rd LAW melter scenario, sodium recycle, aluminum removal, and various supplemental treatment technologies? (For example, if Early LAW was implemented and sodium recycle incorporated, what capacity requirements would then exist for BV, which tanks would be treated, and what equipment cost would be incurred? If this analysis has not occurred, is it scheduled to occur with adequate time to avoid unnecessary costs?)
6. Are decision points scheduled for options and alternatives with adequate time for analysis and to modify current construction, or to develop, construct, and test the necessary technology alternatives to meet throughput requirements?
7. Are infrastructure and support operations specified (such as Heating, Ventilation, and Air Conditioning (HVAC), energy supply, transport, and storage), including capacity requirements for each scenario, as well as cost and schedule requirements?
8. What are the advantages and disadvantages of Early LAW treatment?
9. What are the advantages and disadvantages of supplemental LAW treatment?
10. What are the system and technology needs and options to achieve Early LAW treatment and supplemental LAW treatment?

Transuranic (TRU) Processing and Disposition

11. Are requirements specified for processing tank waste as TRU, including the determination of which tanks will undergo this processing, technology required, schedule requirements with necessary regulatory decision points, and determination of alternative disposition and requirements (e.g., will WIPP accept the wastes)?

5.0 OVERVIEW OF KEY PROGRAMMATIC ISSUES AND DECISIONS

The key programmatic issues and decisions that provide the context for this review can be summarized as follows:

1. *What is the LAW treatment capacity required to achieve completion of LAW treatment over the same project duration as required for HLW treatment?* Potentially, waste retrievals and tank farm system transfers, waste pretreatment, HLW vitrification, or LAW vitrification may be the rate-limiting process step that determines the overall WTP mission duration. Under the current system configuration, LAW vitrification is the rate-limiting step unless additional LAW vitrification capacity is added or process modifications are made to reduce the needed LAW treatment capacity. The amount of sodium to be processed as part of the LAW stream is the central determinant in the amount of additional LAW treatment capacity needed to meet mission duration goals. Adding additional LAW treatment capacity has the potential to shift the rate-limiting step to either waste retrievals and tank farm system transfers, or HLW pretreatment.
2. *Should WTP LAW vitrification be started prior to the completion and startup of the full WTP?* Currently, the WTP LAW vitrification facility is scheduled for construction completion in 2014, while completion of construction and start of radioactive waste operations for the entire WTP facility is scheduled for 2019. Beginning WTP LAW vitrification earlier than the rest of WTP operations requires providing (a) WTP modifications to facilitate early LAW operations (e.g., process control facility or process flow diversions); (b) interim pretreatment to separate cesium and actinides from LAW; and (c) interim capacity to manage secondary waste from LAW operations. This option may be attractive because it provides added LAW treatment capacity through earlier operations, demonstrates progress in waste treatment, and staggers WTP facilities startup and workforce development needs. Cost, schedule, and technical constraints may make this option unattractive.
3. *What are the practical options for upgrading the capacity of the WTP LAW vitrification facility?* Increased capacity at the WTP LAW facility may be attractive because of the potential to reduce or eliminate the need for construction of additional vitrification facilities with the attendant capital and operating costs. The current facility design includes two melters, while preserving the space for adding a third melter. Options under consideration include adding a third melter, upgrading the capacity of the two melter system, or possibly a mix of current and enhanced melters in a three-melter configuration. Implementation of each of these options will entail modifications to the balance of the LAW vitrification facility, such as increased electrical supply and cooling capacity. Modifications also will delay facility completion. Cost and mission completion date compared to other options may make this option unattractive.
4. *What approach should be taken to minimizing the lifecycle programmatic costs while achieving essential long-term human health risk reduction and environmental protection?* The approach likely requires a combination of reducing the need for additional LAW treatment capacity and innovative technical approaches to improving LAW treatment efficiency. This includes consideration of alternative pretreatment

approaches (e.g., in-tank and near-tank separations for actinide and cesium removal, fractional crystallization for sodium separation), alternative vitrification processes (e.g., BV), alternative immobilization technology for pretreated portions of LAW and secondary waste (e.g., cementitious waste forms), and reduction in uncertainty and bias in the performance assessment for on-site disposal of treated LAW.

All of these issues and subsequent decisions are interdependent and limited by cost, schedule, technical, regulatory, and public acceptance constraints. Thus, an integrated systems strategy and approach, along with tools to model and analyze different scenarios, are needed to guide programmatic decisions, technology development, and successful mission completion. In this report, current technology options are considered, including potential benefits, limitations, and uncertainties, followed by a comparative analysis of several possible scenarios based on schedule for mission completion and life-cycle cost (on a present worth basis), with the intent of informing—not recommending—subsequent management decisions.

6.0 RESULTS AND DISCUSSION

6.1 ORP SYSTEMS PLAN, STRATEGY, AND APPROACH

ORP SYSTEMS PLAN

To aid in project management and technical decision making, ORP has developed—and continued to revise and update—a “System Plan” that addresses the full scope of its mission to safely store, retrieve, and treat the Hanford site’s radioactive tank waste and then close the tank farms to protect the Columbia River. The System Plan describes and analyzes a “Reference Case” for execution of the mission, and then evaluates additional scenarios that impact key issues and uncertainties.

The Reference Case approximates key features of the current project scope and its underlying technical basis; however, it is not an exact replication of the current project baseline. It presents an analysis of a particular set of technical decisions and assumptions that allow ORP to complete its mission in a reasonable timeframe (present estimates indicate between 23 and 35 years). The Reference Case assumes that the WTP will, when fully operational, perform better than the present contract requires with respect to throughput and waste loading. It also assumes that supplemental LAW treatment capacity will be established so that the LAW treatment mission is completed at approximately the same time as the HLW treatment mission. It also assumes that required regulatory approvals will be obtained to process some waste as TRU waste, that which contained appropriate levels of transuranic elements, for disposal at WIPP.

The System Plan also describes options to the Reference Case that are being evaluated by DOE. These include starting LAW treatment earlier than HLW treatment to take advantage of the projected earlier completion date for construction of the LAW vitrification facility than the planned completion date for the HLW treatment facility (ca. five years); the recycling of caustic solutions used in waste processing; several possible SST retrieval scenarios; several supplemental treatment options, including utilization of a second LAW treatment facility; and the role that an interim pretreatment system could play in accelerating mission completion. Each of these options is qualitatively described, their potential impact on mission completion

evaluated, and the relative benefits of each option described. Sensitivity analyses are also performed.

Finally, key issues and uncertainties that pertain to completing the ORP mission are described. Along with each key issue and uncertainty, the System Plan discusses the assumptions in the analysis that address the issue or uncertainty. Also, mitigation actions for each issue or uncertainty are described.

The System Plan relies on the HTWOS model to simulate the performance of the planned HLW tank farm operations, including waste retrievals, transfers, and tank-farm based processes (e.g., evaporator and interim pretreatment), and WTP operations. Results of these simulations provide the basis for scenario evaluation and development of mitigation strategies. Additional discussion of the HTWOS model and limitations is provided below.

ORP STRATEGY

A key element in DOE's strategy for completing the Hanford site tank waste treatment and immobilization mission is to complete the treatment, immobilization, and disposal of the tank waste in a timely and cost effective manner (ORP-11242, Rev 3).⁸ DOE's strategy is to complete the Hanford WTP PT, HLW, and LAW pretreatment and immobilization missions within the lower to mid-range of its current Hanford tank waste treatment and immobilization mission duration estimates; i.e., within 23 to 35 years following the start of full WTP hot operations in 2019. DOE is identifying and testing supplemental, low-activity, waste immobilization technologies and approaches with the objective of achieving the mission duration strategy and increasing the overall robustness of its LAW immobilization capabilities and its operational flexibility.

DOE's strategy and priorities for completing the Hanford site tank waste treatment and immobilization mission are as follows:

1. Complete WTP construction and commissioning by 2019.
2. Complete construction of the WTP facilities that support the ability to process LAW using a minimum of one of the two melters by 2014. Continue retrieval at a rate sufficient to develop technologies and maintain a proficient staff to support ramp up of the retrieval rate after WTP start-up
3. Complete development of the IPS to support early start-up of WTP LAW and a supplemental LAW facility (e.g., BV)
4. Continue development of the BV technology through cold testing to support supplemental processing of LAW through the interim pretreatment system. The BV system could be scaled up in the future to process the balance of LAW feed from the WTP pretreatment facility.
5. Develop a program for SST integrity. Actions need to be taken to increase the confidence that the tanks will be structurally sound and leaks to the environment due to corrosion are minimized for the duration of the RPP mission.

⁸ CH2M Hill, ORP-11242, Revision 3, "River Protection Project System Plan," P.J. Certa, et al., CH2M HILL Hanford Group, Inc. May, 2008.

TIMELINE FOR KEY DECISIONS

A series of time-phased decisions are necessary to (i) implement the current plan and process changes, (ii) initiate LAW processing prior to completion of the entire WTP facility, (iii) provide supplemental LAW treatment capacity, or (iv) enhance the capacity of the present LAW vitrification facility. Figure 3 depicts the timeline for key programmatic milestones.

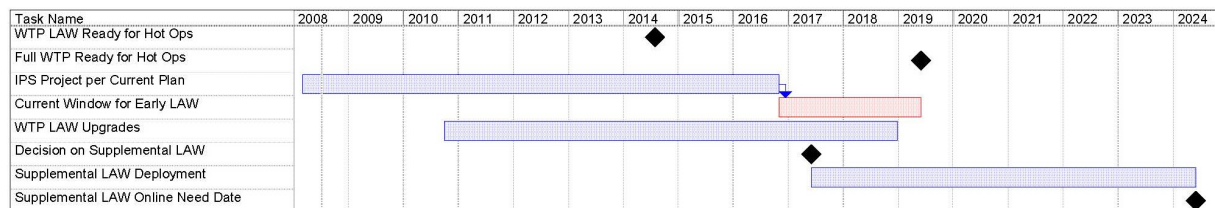


Figure 3. Currently Projected Timeline for Key Programmatic Milestones

Key program elements that impact decisions about LAW treatment strategies are listed below:

1. WTP LAW construction and systemization completion (ready for radioactive waste processing) by 2014. However, current systems planning indicates that interim pretreatment requires four to seven years to implement based on both technical (design, procurement, and construction) and administrative (DOE reviews and approvals, and regulatory approvals) schedules. A four-year implementation cycle would allow processing to begin in 2014, resulting in five years of WTP LAW operations prior to full WTP operations beginning in 2019. This scenario is the most optimistic and is based on the SRS experience with the modular contactor unit (MCU) for cesium separations (start up in 2008). The most pessimistic scenario is that a seven-year lead time is required to implement IPS and includes significant near-tank construction. This scenario would allow only three years of WTP LAW operation prior to full WTP operations. Use of in-tank and small-scale processing options could shorten the construction cycle, but potentially not shorten the administrative and regulatory review cycles.
2. WTP LAW upgrades (third melter or enhanced two melter options) delay WTP LAW completion until 2019, assuming a rapid decision to pursue this option. Thus, either early LAW operations or LAW upgrades potentially could be implemented; both early LAW operations and LAW upgrades cannot be selected.
3. A selection decision for supplemental treatment is not needed until 2017 to achieve operations by 2024, the projected need date, and assuming seven years for implementation. The interval between now and 2017 allows for reduction in the uncertainty of the amount of supplemental LAW treatment capacity needed and the evaluation of technical alternatives and scenarios to achieve the needed additional capacity.
4. The decision whether to implement either early LAW or LAW upgrades must be made soon to take advantage of windows of opportunity within the current schedule. A delay in selecting either option would substantially reduce or eliminate the potential benefits of either option. However, it is not necessary to select either early LAW or LAW upgrades (both options can be declined) and the mission duration goals can still be achieved through selection of appropriate capacity for supplemental LAW treatment in 2017.

Additional important program elements that impact the overall mission schedule and uncertainty include the following:

1. Implementation of tank farm infrastructure upgrades needed to provide timely waste feed to WTP. Current planning provides insufficient emphasis and distinction to essential system upgrades to meet feed requirements for WTP operations in contrast to judicious landlord practices.
2. Schedule for regulatory approvals as needed for implementation of WTP, Early LAW including IPS and interim management of secondary waste (if selected), secondary waste management (for full WTP operations), supplemental LAW processes, and on-site disposal of treated LAW and secondary wastes at the IDF. The first step required in many of these approvals is issuing the environmental impact statement currently under development for ORP. Subsequently, the performance assessment for IDF and the associated waste acceptance criteria have the potential to significantly impact WTP operations.
3. Coordination and approvals needed for packaging, off-site shipment, and disposal of TRU waste from the tank farms at WIPP. Currently, the disposal of tank waste TRU from ORP is not on the schedule for WIPP operations and further coordination is required between ORP and WIPP for achieving disposition of the designated wastes, including regulatory review and ensuring that shipment from ORP is timely for WIPP disposal schedules.

HANFORD TANK WASTE OPERATIONS SIMULATOR (HTWOS)

HTWOS is a computer-based operations planning simulator that includes consideration of waste type, quantity, composition, and location contained in each SST and DST, tank farm infrastructure configuration, waste retrieval constraints, and anticipated WTP performance. Based on underlying rules and constraints (e.g., waste loading in glass, individual tank capacity, connectivity of individual tank farm, and WTP components), HTWOS is a valuable tool for evaluating overall ORP system performance (i.e., tank farm operations, WTP, supplemental treatment, early LAW) for a wide range of scenarios.

HTWOS use and utility is currently constrained by the following factors:

1. The HTWOS model has been developed on the same modeling platform as the WTP operations simulator being used for more detailed simulation of the WTP flowsheet (e.g., detailed transient simulation of individual WTP unit operations and their integration) for design and operations planning. The WTP operations simulator does not include integration with tank farm operations (such as retrievals or transfers). As a result, the WTP operations simulator and design basis for WTP operations is updated more frequently than the HTWOS model, and the HTWOS model contains outdated processing assumptions.
2. The lag time between establishing reference case parameter sets for the HTWOS simulations (including DOE review and approval) and completion of model runs and documenting results exceeds two years. This lag time is apparently a consequence of (i) administrative review procedures, (ii) model parameterization and execution procedures or requirements, and (iii) model run documentation processes.

3. HTWOS provides integrated simulation of both tank farm operations and WTP operations, but currently does not have the ability to carry out robust uncertainty characterization (stochastic analysis) nor rigorous optimization to meet defined program objectives (e.g., optimization of tank blending sequences).
4. Limited personnel with capability or dedicated to systems modeling. The current level of effort is approximately one to two FTEs.

The availability of a robust simulator for integrated operations is essential for efficient management decision making and future operations. Detailed scrutiny of the assumptions made to date to permit HTWOS implementation, modeling efficiency, uncertainty characterization and optimization approaches, and linkages between model capability and use with management needs and administrative procedures should be carried out through a separate independent technical review. Consideration should be given to benchmarking simulation efforts for analogous major projects outside of DOE. Follow-up steps should be taken as needed to facilitate much more rapid completion of case analyses and greater utility as a management decision tool.

6.2 UNCERTAINTIES THAT IMPACT PROGRAM NEEDS, SCHEDULE, AND COST

ADMINISTRATIVE AND PROGRAM MANAGEMENT UNCERTAINTIES

The availability of sufficient LAW processing capacity may be limiting to WTP mission completion, thereby extending the mission duration by several years or decades, if current uncertainties are not reduced and balanced processing capability is not available. Waste retrieval, especially from presumed leaky tanks, also may be rate limiting. Currently, the construction of LAW and Analytical Laboratory facilities at WTP are scheduled for completion in 2012 and the pretreatment and HLW vitrification facilities and balance of the plant are scheduled for completion in 2017, with radioactive waste processing scheduled to begin in 2019. After initiation of radioactive waste processing in the HLW vitrification facility, it has been estimated that 23 to 35 years will be required to complete processing if the HLW vitrification is the rate limiting process to mission completion. There are several administrative, programmatic, and technical uncertainties that can impact the mission duration and completion dates. The administrative and program management uncertainties that can result in significant delays in either the beginning of full WTP radioactive waste processing or completion of the mission are as follows:

1. *Program planning and priorities prior to beginning of initiation of radioactive waste processing.* Tank farm infrastructure upgrades, evaporator maintenance, and waste retrieval operations from HLW tanks must be implemented on a schedule that supports timely start up of overall WTP operations in 2019. A careful evaluation needs to be made of the present evaporator to determine if it needs to be replaced, especially because it represents a single point failure mode for tank farm operations. Current planning does not clearly support these requirements to the extent necessary to support start up operations in 2019.
2. *Program planning and priorities after initiation of full WTP radioactive waste processing.* After initiation of full WTP radioactive waste processing, there will be programmatic needs for (i) waste retrieval infrastructure upgrades and operations,

(ii) additional storage capacity for vitrified HLW canisters prior to shipment to a national geologic repository for disposal, and (iii) WTP facility upgrades. Failure to provide timely tank farm infrastructure upgrades may result in the ability to supply waste to the WTP facility becoming the rate limiting process to overall mission completion. Delays in the availability of a national geologic repository (currently planned for Yucca Mountain, Nevada) will result in the need to construct new HLW canister storage facilities at a rate of one facility expansion every two years.

3. *Regulatory approval of planned operations and treated waste disposal.* Additional regulatory approvals or permits are required for (i) WTP operations; (ii) disposal of vitrified LAW on-site at Hanford in the IDF; (iii) acceptance of vitrified HLW for disposal at Yucca Mountain; and (iv) disposal of TRU retrieved from tank farms at the WIPP in Carlsbad, New Mexico.
4. *Planning and implementation for timely availability of supplemental LAW treatment capacity, if needed.* There currently is considerable uncertainty about the schedule and capacity needed for supplemental LAW treatment and the technology choices that should be used to provide supplemental LAW treatment (see further discussion later in this report). Notwithstanding these uncertainties, failure to provide resources for adequate design and planning, along with timely implementation of supplemental LAW treatment capacity could result in schedule extension of the WTP mission. Insufficient LAW capacity would result in LAW treatment becoming the rate limiting process for overall mission completion and potentially may extend overall mission completion.
5. *Administrative plant outages in response to accidents and plant upsets.* Operating outages at WTP and tank farms, in response to either accidents or plant upsets, currently are not explicitly included in systems modeling and schedule planning; instead, a contract-mandated WTP availability (70 percent) is uniformly imposed. Operations at similar or related facilities (SRS, West Valley, or foreign facilities), as well as plant history at ORP, could be used to estimate the frequency and duration of such outages.

TECHNICAL UNCERTAINTIES

The technical uncertainties that could result in significant delays, with attendant cost increases, in either the beginning of full WTP radioactive waste processing or completion of the mission are as follows:

1. *The amount of sodium to be processed as part of LAW treatment.* The amount of sodium to be processed as part of LAW treatment directly impacts the overall amount of vitrified LAW that will be produced, and the time required for LAW mission completion based on available LAW treatment capacity. This is because sodium limits the overall waste loading in the vitrification process. Sodium is part of the waste stream because of its use in the form of sodium hydroxide from prior processing and corrosion control, both of which contribute to the current sodium inventory in the tank farms, and the use of sodium hydroxide as part of HLW pretreatment to remove aluminum and chromium in the WTP. The amount of sodium currently in inventory within the tank farms is known with reasonable certainty. The amount of sodium that will result from HLW pretreatment currently is more uncertain, resulting in a higher uncertainty in the overall amount of sodium to be processed. Uncertainty in the amount of free hydroxide, and the amount

and speciation of aluminate in the tanks, further increases the uncertainty in the amount of sodium hydroxide that will need to be added during pretreatment. The uncertainty in the amount of sodium hydroxide to be added is also increased because of current limitations in the thermodynamic and kinetic models used for estimating processing requirements. Initial estimates for overall sodium requiring treatment as LAW were 60,000 MT, but recent estimates range between 60,000 to 90,000 MT of sodium. Based on a 35-year mission, and contractual facility performance requirements, the current LAW treatment capacity is approximately 40,000 MT sodium. Several ORP and EM headquarters efforts and initiatives could significantly reduce the uncertainty associated with the amount of sodium to be processed: (i) improvements in the estimates of sodium required for pretreatment under the current flowsheet, through better engineering analysis and pretreatment pilot plant (PEP) studies; (ii) flowsheet modifications to reduce usage, recycle, or recover sodium hydroxide; and (iii) treatment of the waste in-tank or near-tank in the tank farms to reduce the inventory of sodium transferred to the WTP. These initiatives are in early stages and will likely take at least 2 years to provide substantial reduction in uncertainty.

2. *Tank farm waste retrieval rates.* HTWOS has been used to evaluate tank waste retrieval scenarios and estimate retrieval rates based on the current tank farm configuration and a limited set of infrastructure improvements. Several recent scenarios indicate the potential for tank farm waste retrieval becoming the overall rate limiting process for overall WTP mission completion. Retrievals from presumed leaking tanks (67 SSTs) are assumed to require the Mobile Retrieval System, a relatively slow retrieval technology that causes waste retrieval to potentially become rate limiting for WTP mission completion. HTWOS simulations to-date assume up to seven concurrent tank retrievals and a learning curve for tank retrieval rates, which significantly exceed demonstrated capabilities during prior operations. Furthermore, additional infrastructure improvements (such as additional cross-site transfer lines, or additional intermediate retrieval vessels) and impacts of potential flow sheet changes (such as selective in-tank pretreatment) remain to be explored.
3. *Glass composition and waste loading rate improvements.* Improvements in the waste loading, especially for aluminum, in HLW glass can reduce the amount of HLW requiring pretreatment and the required LAW treatment capacity. Improvements in the waste loading, especially for sodium, in the LAW glass also could reduce the required LAW treatment capacity. Scenarios evaluated to-date have been based on a LAW waste-loading model that projects lower waste loading in LAW glass than has been demonstrated through recent studies. Formulations that allow higher waste loading are being evaluated and once fully developed may be adopted by WTP as a design or operational basis. Mission scenarios that include the recently demonstrated higher waste loading are being developed. Simulations that consider higher waste loadings based on results from recent laboratory testing were run by ORP in support of this review.
4. *WTP facility HLW and LAW glass production rates.* The currently contracted glass production rate capacity for HLW melters is 7.5 MT per day with an availability of 70 percent. The current contracted glass production rate capacity for LAW melters is 30 MT per day with an availability of 70 percent. The production rates for both the overall HLW vitrification systems and the overall LAW vitrification systems are subject to uncertainty

from various sources, including assumed availability. There also appears to be potential to increase the nominal glass production rate capacity for LAW melters to 45 MT per day with an availability factor of 70 percent (see discussion in subsequent sections of this report). Up to date comparative analyses of overall system availability for related radioactive waste vitrification processes are not available (for example, comparison with the system availability at SRS, WV, and foreign systems).⁹

5. *WTP pretreatment system capacity.* Prior reviews have identified several concerns that could significantly impact the overall performance of the WTP pretreatment system. These concerns are being actively pursued through a series of issue response plans, but the results of these evaluations and technology maturation will require approximately two years to complete. In addition, any potential temporary shut-down of the WTP pretreatment system, under the current configuration, represents a single point failure mode that would result in the shutdown of the entire WTP processing plant. Supplemental pretreatment capability could alleviate this single point failure mode.

6.3 LAW PROCESSING REQUIREMENTS

Aluminum and chromium present in the HLW tanks at Hanford if not removed would substantially increase the number of vitrified HLW waste canisters sent to a geologic waste repository because of current limitations to aluminum and chromium loading in HLW glass. Ongoing research may define HLW glass formulations with increased aluminum and chromium loading. Aluminum is present in the HLW tanks primarily as gibbsite $[\text{Al}(\text{OH})_3]$ and boehmite $[\text{AlO}(\text{OH})]$, but there are a large number of other aluminum compounds present, including some compounds (e.g., refractory aluminosilicates) that are resistant to leaching. Removal of aluminum from HLW results in a substantial increase in the amount of sodium to be processed in LAW because of the addition of sodium hydroxide to increase aluminum solubility and prevent corrosion. Removal of chromium also results in substantial increases in sodium to be processed as LAW because of pH adjustments necessary to carry out chromium leaching without co-solubilizing plutonium. As a result of projections of aluminum and chromium leaching process performance, and sodium loading constraints in LAW glass, reducing the amount of sodium required for HLW pretreatment is central to minimizing the amount of additional LAW treatment capacity needed.

LAW CAPACITY AND PERFORMANCE REQUIREMENTS

The quantity of LAW treatment capacity required is expressed in MT of sodium (MT Na) because sodium is the LAW constituent that limits waste loading in the resultant glass for most cases (for some LAW, sulfur or other constituents may limit waste loading). Figure 4 illustrates the interdependence of LAW treatment capacity, mission duration, and quantity of sodium to be treated. One important observation is that completion of the mission by, as currently planned, 2049 requires total net vitrification capacity of at least 40 MTG per day for the case of 60,000 MT Na, and at least 52 MTG per day for the case of 90,000 MT Na, respectively, to be treated to form vitrified LAW. Additional capacity would be needed if other processing requirements

⁹ Care must be taken to ensure that system availability data are tracked on a common basis to provide useful information for comparison between facilities.

(e.g., retrieval, pretreatment, or net system availability less than the assumed 70 percent) further restricted net processing rate. The current WTP LAW facility provides only 21.5 MTG per day net vitrification capacity assuming 70 percent system availability. Clearly, the amount of sodium to be processed, waste retrieval rates, realized net system availability, and desired mission duration have large impacts on the amount of supplemental LAW treatment capacity required.

Performance requirements for LAW treatment are based on (i) a technology-based treatment agreement (policy decision) with the State of Washington to vitrify LAW prior to on-site disposal; and, (ii) agreement with the NRC to remove radionuclides to the extent technically and economically feasible, meet low activity waste Class C disposal requirements, and demonstrate that the disposal waste form will be protective of human health and the environment through a performance assessment of the disposal scenario (i.e., vitrified LAW disposal in the IDF at Hanford). Conservative assumptions (e.g., intentionally over-estimating release and risk) in the performance assessment are used to support this decision.

Alternative approaches to treatment have been suggested and may meet risk criteria based on performance assessment, but they are currently precluded based on agreed policy. A recent paper authored by Washington Department of Ecology suggests the potential approach to tailor LAW treatment approaches and requirements based on defining waste composition envelopes to improve overall LAW treatment and disposition efficiency.¹⁰ This suggestion may represent an opening to significant policy adjustments and warrants further exploration by DOE.

¹⁰ R.K. Biyani. Lessons Learned in the Technology Development for Supplemental Treatment of Low-Activity Waste at Hanford, *Waste Management 2008 Conference*, Phoenix, AZ, Paper 8379.

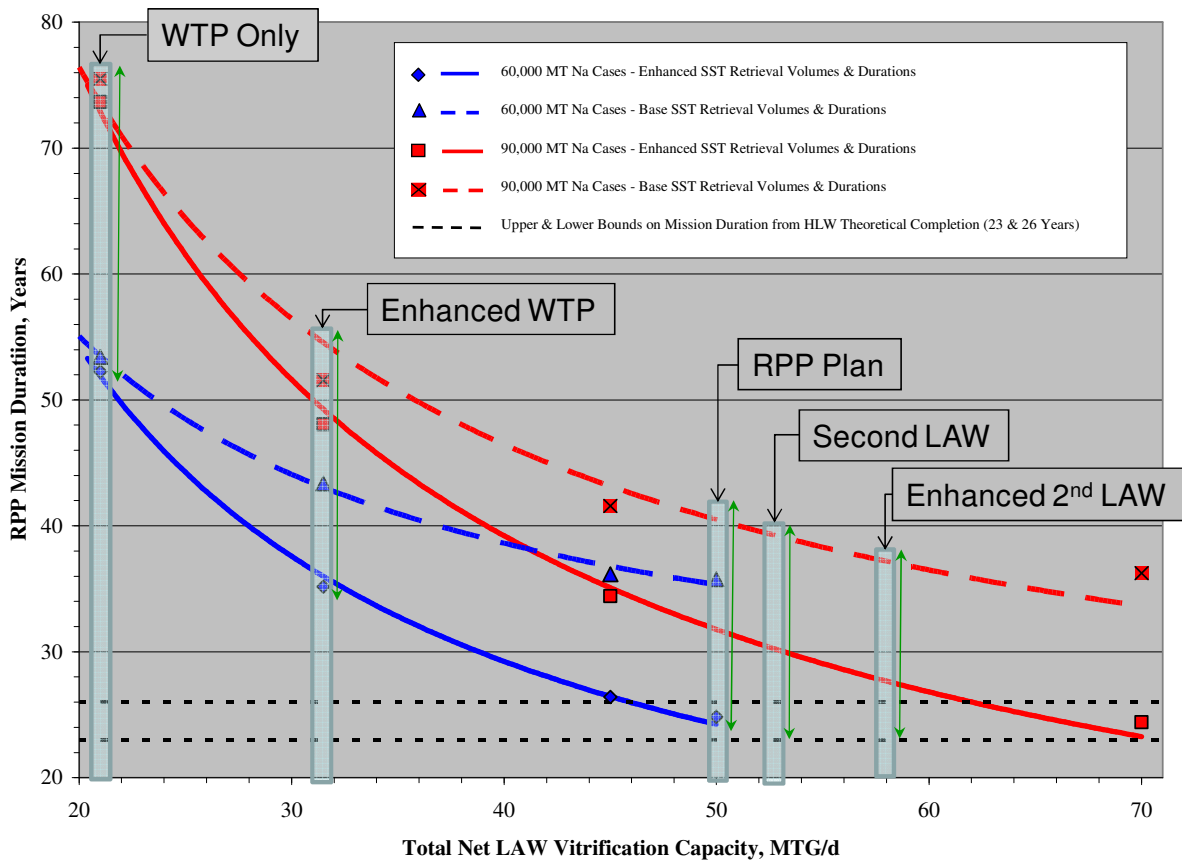


Figure 4. Illustration of Relationship Between Total Net Vitrification Capacity and Treatment Duration (*after M. Knight and J. Honeyman, CH₂M-Hill, 2008*).

The blue lines (solid and dashed) in Figure 4 represent mission duration estimated for 60,000 MT sodium (solid and dashed lines indicate LAW treatment capacity rate limited and waste retrieval limited cases, respectively). Red lines represent mission duration estimated for 90,000 MT sodium to be vitrified (solid and dashed lines indicate LAW treatment capacity rate limited and waste retrieval limited cases, respectively). Vertical highlighted bars indicate cases examined in this study, while the black dashed lines represent the range of mission duration (in years) if the mission duration was based solely on HLW vitrification treatment capacity. An average sodium oxide loading of 19.7 wt percent in vitrified LAW was assumed to generate these curves. An example case for reading this figure is for Enhanced WTP and 60,000 MT sodium when waste retrieval limits mission duration (i.e., blue dashed curve at 31.5 MTG per day [x-axis]) results in a mission duration of approximately 43 years [y-axis].

CAPACITY AND PERFORMANCE REQUIREMENTS FOR INTERIM AND SUPPLEMENTAL PRETREATMENT

Primary HLW pretreatment capability for tank wastes is to be provided by the WTP Pretreatment Facility, which is scheduled to initiate radioactive waste processing in 2019. WTP Pretreatment

nominally has been sized to pretreat all tank waste prior to vitrification at a capacity consistent with planned HLW vitrification rates and approximately 27 to 35 year WTP mission duration. WTP Pretreatment includes capability for (i) solids separation using cross-flow ultrafiltration (primarily for separation of insoluble actinides); (ii) caustic and oxidative leaching to remove aluminum and chromium, respectively, from HLW; and (iii) ^{137}Cs removal from LAW by ion exchange using resorcinol formaldehyde (RF) resin.

Additional pretreatment capability (termed “interim pretreatment”) will be needed if the management decision is made to proceed with radioactive operations for LAW vitrification prior to completion of the full WTP plant (Early LAW). This is because WTP Pretreatment would not be available at the necessary time (in 2014). Interim pretreatment would require solids separation, for actinide and Sr removal, and a ^{137}Cs removal step. The nominal capacity of interim pretreatment would be based on the operating capacity of the WTP LAW facility.

Current planning indicates that WTP LAW vitrification may be available for radioactive processing as soon as 2014, five years earlier than the planned WTP full plant availability of 2019. Planning estimates for providing interim pretreatment presently provide a seven-year lead time, with starting conceptual design in 2008 to result in interim pretreatment facility availability in 2015. Current ORP estimates project a starting date for conceptual design of 2009, which would result in interim pretreatment availability in approximately 2016. For comparative purposes, the Modular Caustic Side Solvent Extraction Unit (MCU) developed at SRS for ^{137}Cs removal from LAW required 4 years to implement, which has been described as a highly streamlined effort. The time required for implementation is independent of technology to a large extent, but rather is dominated by design processes, technology maturation, and regulatory and other reviews if the new capability is established either in-tank or near tank with a modest footprint. A potentially significant schedule impact could be the needed regulatory approvals that first require issuance of the Environmental Impact Statement for RPP and then proceeding with process specific permitting for Early LAW and IPS.

Removal of ^{137}Cs from waste destined to become vitrified LAW is predicated in part on meeting a prior agreement between DOE and NRC: “DOE's 1997 agreement with the NRC to enable LAW disposal onsite requires two primary pretreatment functions: (i) solid/liquid separation to assure that solid sludges bearing strontium and TRU are separated from the feed, and (ii) cesium removal to the extent technically and economically practical (in their deliberations, they determined that removal of cesium to 0.05 Ci/L in a 7M sodium solution met this standard). In addition, DOE must meet “equivalent to NRC Class C standards,”¹¹ and complete a performance assessment demonstrating that the disposal systems (glass and burial system) are protective of human health.¹² In practice, levels lower than these are required because of ALARA dose requirements for operating and maintenance personnel and facility shielding design.

Cesium-137 removal from LAW for interim pretreatment requires achieving a LAW ^{137}Cs concentration of $\leq 2.8 \times 10^{-4}$ Ci per gallon, which is based on safety and shielding design of the

¹¹ 10 CFR Part 61, “Licensing Requirements for Land Disposal of Radioactive Waste,” § 6155, Waste Classification.

¹² C. J. Paperiello, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, to J. Kinzer, U.S. Department of Energy, Richland Operations Office, Richland, Washington, “Classification of Hanford Low-Activity Tank Waste Fraction”, letter dated June 9, 1997.

WTP LAW facility. Current planning is considering obtaining LAW feed either from DSTs or SSTs. Providing feed from the existing DST supernate represents the simplest approach because of the quantity of LAW present in DSTs to be treated and the limited extent of infrastructure upgrades required. Cesium decontamination factors have been provided for all of the SSTs and DSTs.¹³ In general, the required revised decontamination factors are less than 2000, often much less. Six tanks require factors slightly over 2000, and tank 241-AZ-102 requires a decontamination factor of about 24,000. Providing feed from the SSTs would reduce the decontamination factor needed, but require more extensive infrastructure upgrades and could add operational complexity.

Table 1 compares the pretreatment targets for ¹³⁷Cs concentrations for feed to the LAW glass melters at Hanford and to the Saltstone preparation process at the Savannah River Site.¹⁴ In general, the compositions of the Hanford tanks wastes are more highly variable from tank-to-tank than are the compositions of the SRS tank wastes. This is a consequence of the Hanford tanks containing wastes from more diverse separations processes (BiPO₄, U recovery, REDOX, PUREX, Pu product/fabrication/recovery, Cs and Sr recovery and encapsulation) than were used at SRS (basically just the PUREX process). Of particular importance is the fact that the REDOX process at Hanford used high concentrations of aluminum nitrate as a salting agent to enhance plutonium extraction. The resultant high aluminum content in some of the tanks and methods for its removal have become very important considerations in determining the number of DOE HLW canisters of vitrified waste destined for the proposed Yucca Mountain geologic repository.

Table 1. Comparison of Cesium-137 Removal Requirement for LAW Pretreatment at WTP (Hanford) and SWPF (Savannah River)

	Target ¹³⁷ Cs in feed and LAW product	Feed source	<u>Cs DF</u> Average	<u>Cs DF</u> design maximum	Primary reason for pretreatment target
Pretreatment requirement for WTP LAW vitrification (Hanford)	2.8E-04 Ci/gal feed (0.3 Ci/m ³ in Glass)	All Hanford supernate, saltcake, and HLW Sludge	1,110	24,400	WTP LAW ALARA (contact maintenance and operation of LAW melers and canisters)
Pretreatment requirement for SWPF to produce saltstone (Savannah River)	2.1E-04 Ci/gal feed (45 nCi/gm in Saltstone)	All SRS supernate and saltcake	1,700	40,000	Disposal waste form Criteria (original Class A target for saltstone)

Additional pretreatment capacity beyond WTP Pretreatment is not necessarily required if additional LAW treatment capacity (i.e., supplemental treatment) is implemented, but it may be

¹³ Michael E. Johnson, "Cesium Decontamination Factor Analysis for SST and DST Wastes," CH2M HILL Hanford Group Inc., March 24, 2008.

¹⁴ Taken, with modifications, from "Hanford/SRS LAW Pretreatment Strategy," a PowerPoint presentation prepared for Ines Triay, April 2008.

desirable. Provision of additional LAW treatment capacity collocated at WTP could be supplied feed from the WTP Pretreatment facility. Provision of additional LAW treatment capacity near the West side tank farms would require infrastructure upgrades to facilitate cross-site LAW feed transfer from WTP Pretreatment. In addition, there currently is uncertainty about the WTP Pretreatment facility performance¹⁵. Thus, provision of additional pretreatment capability, either near the tanks or in the vicinity of supplemental treatment, if implemented, may be warranted.

UNCERTAINTY IN THE AMOUNT OF SODIUM TO BE TREATED

There is significant uncertainty in the amount of sodium to be treated as LAW. Table 2¹⁶ summarizes the present estimates of amounts and sources of sodium and their current planned dispositions. The large increase in the amount of sodium to be added (from 6,500 to 39,700 MT) for aluminum dissolution is indicative of this uncertainty. Sodium is present in the waste tanks as both sodium nitrate and sodium hydroxide and other species. Uncertainty about the amount of sodium in LAW to be treated arises from the following:

1. Uncertainty in the waste composition currently in the tanks. The amount of sodium currently in the tanks is reasonably well known. However, significant uncertainty exists regarding the amount of free hydroxide and the speciation of aluminum (i.e., quantification of the amounts of gibbsite $[\text{Al}(\text{OH})_3]$ and boehmite $[\text{AlO}(\text{OH})]$), both of which will impact required sodium hydroxide additions during pretreatment.
2. Sodium to be added during pretreatment. Limited data on actual wastes and surrogates results in uncertainty in solubility and kinetic models for aluminate as a function of temperature, free hydroxide, aluminate speciation, and bulk waste composition.

Current estimates of sodium include bias to provide “conservativeness” for WTP design calculations (e.g., design contingency margin) that may not be appropriate for systems level decisions, especially without explicit quantification of uncertainty and bias. For example, up to a multiplier of two or greater bias is inherent in assumptions of free hydroxide for current tank waste inventory. In addition, there is a bias of up to 30 percent or more associated with current thermodynamic solubility models for aluminate during pretreatment. Uncertainty reduction can be achieved through improved thermodynamic and kinetic models (requiring new laboratory data), Phase II testing with the pretreatment engineering-scale pilot (PEP), and exploration of potential flowsheet modifications.

¹⁵ See External Review of the WTP Flowsheet.

¹⁶ Jim Wicks, “Management of LAW Na in River Protection Project (RPP) System,” May 5, 2008.

Table 2. Sodium Sources, Amounts, and Planned Dispositions or Uses

Na Source or disposition route	60,000 MT Na case tank farm baseline RPP-06-003	90,000 MT Na case WTP contract case, TFCOUP feed vector, Rev 6.0
Na from tank farm to WTP, MT	35,870	37,020
Na added in pretreatment for Al dissolution	6,500	39,700
Na added in WTP for process stream conditioning	2,600	5,300
Na immobilization in west area ST	11,560	9,970
Na immobilized as TRU	530	660
Total Na, MT	57,060	92,550
Total Na, MT (rounded)	60,000	90,000

OPTIONS FOR REDUCING THE AMOUNT OF SODIUM TO BE TREATED

Sodium hydroxide and sodium nitrate are a major source of sodium in the Hanford tank wastes and are a major problem for LAW vitrification because the sodium is a limiting constituent in waste loading into vitrified LAW. Several methods are in early stages of concept evaluation for the removal and recycle of sodium (present as NaOH and NaNO₃) from the ILAW. These include the WTP Leaching Process,¹⁷ Modified Bayer Process,¹⁸ Caustic Management Aluminum Removal (Lithium Precipitation) Flowsheet,¹⁹ Continuous Sludge Leaching Process, Electrochemical Salt-splitting Process,²⁰ and sodium nitrate crystallization.²¹ Four of the processes require the use of caustic solutions to dissolve the solid aluminum compounds. In the extreme case the amount of caustic (NaOH) required is very large, possibly in excess of 90,000 MT Na.

The Waste Treatment Plant Leaching Process

The flowsheet currently embodied in the WTP pretreatment facility separates the aluminum into an immobilized LAW vitrified waste (ILAW) for disposal in the IDF on the Hanford site.

¹⁷ Jacob G. Reynolds et al, "The Waste Treatment Plant Leaching Process," October 10, 2007.

¹⁸ Don Geniesse, "Modified Bayer Process for Alumina Removal from Hanford Waste," AREVA NC Inc., January 24, 2007.

¹⁹ G. L. Dunford and A. L. Pajunen, "Caustic Management Aluminum Removal (Lithium Precipitation) Flowsheet," AEM-CTC-2007-FS-012, Rev A, January 29, 2008.

²⁰ G. L. Dunford and A. L. Pajunen, "Caustic Management Electrochemical Membrane Flowsheet," AEM-CTC-2007-FS-011, Rev 0, December 17, 2007.

²¹ Dennis Hamilton, "Alternate Pretreatment Technologies Fractional Crystallization Status," CH2MHILL, June 11, 2008.

Chromium is also of concern because of its effect on the waste loading in the HLW glass and therefore a process step is included for its removal.

The aluminum leaching step in the WTP flowsheet is similar to the Modified Bayer Process, but it is carried out at a lower temperature. It uses concentrated caustic leaching solutions to dissolve the gibbsite and boehmite as anionic aluminate ion. Unlike the Modified Bayer Process, aluminum is maintained in solution rather than precipitated with caustic recovery. Oxidative leaching with NaMnO_4 is used to increase the valence state of the insoluble trivalent chromium hydroxide and thereby dissolve it as the hexavalent anionic chromate ion. Free hydroxide and NaMnO_4 concentrations must be carefully controlled to prevent oxidation and solubilization of any plutonium present. The WTP flowsheet relies on removing plutonium and other actinides as insoluble compounds.

To remove aluminum and chromium from the HLW sludge, the sludge must be treated for about eight hours with 19 M NaOH added to achieve a 6 M NaOH waste solution and heated to approximately 90°C.²² The entire cycle for aluminum and chromium removal requires about 36 hours for heating, leaching, and cooling back down to 25 to 45°C. The amount of caustic (NaOH) required to dissolve the gibbsite and boehmite is large, and there remains significant uncertainty in 90,000 MT Na estimate.

Modified Bayer Process

The Modified Bayer Process uses concentrated caustic solution to leach alumina sludge at temperatures approaching 100°C. Crystalline gibbsite is then precipitated from solution at 60°C by seeding with gibbsite crystals. The process regenerates hydroxide for additional alumina leaching. Seventy-five percent of the theoretical yield is obtained in 24 hours and approximately 100 percent is obtained in 4 days. The process may be enhanced by dilution, partial neutralization, or lithium-alumina-carbonate precipitation to pre-condition liquor for WTP feed. Boehmite is more difficult to remove by leaching and subsequently to precipitate than gibbsite. The Modified Bayer Process is still in the development stage.

Caustic Management Aluminum Removal (Lithium Precipitation) Flowsheet

Experimental work at Georgia Tech demonstrated the viability of the Caustic Management Aluminum Removal (Lithium Precipitation) Process to remove alumina from Hanford HLW tank sludge. The bulk of the alumina in the sludge may be leached by heating to dissolve it in existing supernatant liquor. Addition of lithium hydroxide solution precipitates alumina as a readily separable and washable solid. After filtration of the precipitate, the hydroxide regenerated by the precipitation reaction may be recycled for further alumina leaching, reducing the amount of leach solution (and thus the amount of sodium hydroxide) required for sludge leaching. Efficacy of hydroxide recycle remains to be demonstrated.

The lithium-alumina process is claimed to be more efficient than the Modified Bayer process because it precipitates all soluble alumina without partial neutralization. Thus, the alumina yield is roughly two times higher. It spontaneously nucleates and does not require seed or seed recycle. In the lithium-alumina process, the precipitation occurs within minutes, roughly one hundred times faster than the Modified Bayer method. The lithium-alumina precipitate diameter

²² Leaching at higher temperatures (i.e., closer to 100°C) is being evaluated, but may be constrained by materials of construction limitations.

is approximately 30 times larger and retains less liquid, allowing faster liquor separation and easier decontamination. The resulting hydroxide in the filtrate minimizes the amount of supernatant caustic required to leach the alumina in HLW tank sludge. The solubility of aluminate ion decreases as the liquid phase free hydroxide ion concentration decreases. Therefore, the alumina dissolution reaction stops when the aluminum solubility limit is reached. The impact of lithium on LAW waste loadings needs to be considered as there is a roughly mole-for-mole displacement of sodium capacity in the glass by the added lithium. Furthermore, the maximum acceptable amount of lithium oxide in the glass is considerably lower than for sodium oxide (by about a factor of five on a mass basis). This process is still in the development stage.

Continuous Sludge Leaching Process

The Continuous Sludge Leaching Process is being developed under EM's Advanced Remediation Technology (ART) Program by Parsons Infrastructure & Technology Group and the Pacific Northwest National Laboratory. The process uses a continuously stirred reactor vessel operating with caustic at 90 to 100°C to remove aluminum and chromium, in a near-tank configuration. It will complete preliminary design, bench scale, and engineering scale testing during 2008 and 2009; follow-on work is scheduled to be ready of prototype deployment in 2011. The potential advantages of this approach are that it uses a longer residence time with a smaller footprint than the current semi-batch WTP pretreatment process based on reactor configuration to facilitate more complete aluminum extraction and may be implemented in a near-tank configuration.

Electrochemical Salt-splitting Process

The electrochemical salt-splitting process is based on inorganic NaSICON ceramic membranes. The NaSICON ceramics are polycrystalline materials that possess channels within the crystal structure for Na ion conduction. The channel size is determined by rare-earth ions. These materials are uni-dimensional ionic conductors, so the grain orientation affects the ionic transport rates. The new NaSICON materials are three-dimensional ionic conductors.

In this process, the caustic waste is added to the anode compartment of an electrolytic cell and a direct current electrical potential (<10 volts) is applied to the cell. This drives Na^+ ions through the NaSICON membrane that has channels sized to be selective for sodium. Electric charge balance in the anode compartment is maintained by generating hydrogen ions (H^+) from the electrolysis of water. Charge balance in the cathode compartment is maintained by generating hydroxide ions (OH^-) from the electrolysis of water. Other reactions, such as converting nitrites to nitrates present in the waste solution also occur. The normal gaseous products of the electrolysis of water are oxygen at the anode and hydrogen at the cathode. The concomitant potentially flammable gas mixtures can be prevented by providing adequate volumes of a sweep gas or by oxidizing the hydrogen as it is generated. As hydrogen ions are generated in the anode compartment, the pH drops. As hydroxide ions are produced in the cathode compartment, the pH rises and caustic solution is recovered for recycle. This process is still in the development stage.

Fractional Crystallization

Fractional crystallization by evaporation of water is a promising approach for partial removal of sodium in the form of sodium nitrate from the tank liquid wastes. Sodium nitrate is a major contributor to the tank waste solids, and if not removed becomes a major contributor to the sodium in the LAW waste stream, leading to a large volume of LAW glass and a resultant large number of LAW waste canisters. Depending on feed composition, 20 to 65 percent of the sodium in the feed stream to the crystallization unit may be removed by fractional crystallization. Significant decontamination of the crystallized sodium nitrate is obtained from Cs, Tc, and I, suggesting the potential for final disposal of the sodium nitrate through waste water treatment processing or alternative treatment methods and waste forms.

Traditionally, separation methods in radiochemical operations avoid the use of solid-liquid separations because separation factors are typically low and such separations are more difficult radioactive operations than other more commonly used separation methods such as solvent extraction. In the present case, the rather small single-stage separation factors, in the range of 100 to 150, have been achieved as expected in laboratory, engineering-scale, and pilot plant tests using simulants. In the case of the laboratory tests, actual tank waste has also been used. In laboratory tests, decontamination factors up to 20,000 have been obtained for cesium by using a second crystallization step.²³ This result indicates that successive crystallizations behave ideally, and that DFs are multiplicative. Computer model separation predictions for Na, Cs, Tc, and I using a commercially available computer model²⁴ are well supported by the laboratory tests.

In addition to partial sodium nitrate removal, fractional crystallization holds promise for removing some of the sulfate ion present in the tank waste. The model predicts, and pilot plant experiments confirm, removal of sulfate from the LAW stream as a crystalline sodium sulfate/carbonate salt (burkeite) that remains with the sodium nitrate. In light of the deleterious effect of sulfate ion on glass formation, its removal from the LAW stream is a significant favorable result. However, a disposal pathway for this separate sulfate stream remains to be developed.

A production plant prototype pilot-scale crystallizer has been built and operated at SRNL. The unit was designed for continuous operation at a feed rate of 1.5 gallons per minute and a LAW product rate of one gallon per minute, or about 1/5 of the scale of the SST baseline plant. The feed tanks hold 10,000 gallons of tank waste and the crystallizer holds 1,000 gallons. Crystallized salts are separated from the crystallizer slurry by centrifugation. In pilot plant tests, sodium nitrate forms as large crystals and the sulfate-carbonate salt forms as much smaller crystals. The Cs decontamination factor in a single stage was ~200. Table 3 summarizes the fractional crystallization results to-date.

²³ Dennis Hamilton, "Alternate Pretreatment Technologies Fractional Crystallization Status," CH2MHILL, June 11, 2008.

²⁴ "Environmental Simulation Program," OLI Systems, Morris Plains, NJ.

Table 3. Fractional Crystallization Results²⁵

Species removed	Goal	Computer model prediction	Lab scale simulant tests	Lab scale actual waste	Engineering scale simulant tests	Pilot plant tests (preliminary)
Cs DF	50	110-270	>150	>150	167	~200
Sodium remaining in LAW	50%	70-80%	80%	80%	N/A	52% (70%) ²⁶
Sulfur remaining in LAW	None	N/A	N/A	N/A	N/A	20%
Tc DF	None	Same As Cs	N/A	>150	N/A	N/A
I DF	None	Same As Cs	N/A	>150	N/A	N/A

6.4 INITIATING LAW PROCESSING PRIOR TO WTP COMPLETION (EARLY LAW)

Completion of construction of the WTP LAW processing facilities is contracted and scheduled for 2012, with the potential to begin radioactive waste treatment operations in 2014. The remaining WTP facilities are scheduled for completion in 2017, with the beginning of radioactive waste operations estimated to occur in 2019. This difference in completion schedules provides the potential opportunity to begin LAW treatment before HLW treatment; however, this possible five-year operating interval may decrease if completion of LAW treatment facilities is delayed or increase if completion of HLW treatment facilities is delayed.

The advantages of beginning LAW treatment as early as possible, and prior to beginning HLW treatment, are summarized below:

1. Provides an opportunity to determine LAW performance characteristics and identify potential improvements in facility design and operation in a timely manner to beneficially impact (i) the first cycle of melter replacement (anticipated after five years of operation), early in the mission of HLW treatment; and (ii) the selection and design of supplemental LAW capability, including reducing the uncertainty associated with the estimated needed additional LAW treatment capacity.
2. Free DST space to facilitate more efficient tank farm operations.
3. Provide for early ramp up of tank farm retrieval and transfer operations.
4. Stagger the start up of multiple facilities to provide better ramp up and learning associated with staffing, personnel training, procedures documentation, and technology

²⁵ Adapted from tables in reference 1.

²⁶ Assumes known and avoidable centrifuge losses do not occur.

operations. In addition, the interim pretreatment capacity required by this scenario could provide additional pretreatment capability should such capacity be needed.

Additional considerations with respect to beginning LAW treatment as early as possible are the following:

1. There is a management disadvantage to not beginning LAW treatment as early as possible: it will be difficult to justify an idle facility to multiple DOE constituencies. Conversely, successful start up of LAW treatment provides tangible demonstration of progress in stabilizing the ORP inventory of radioactive waste. However, early start up of LAW treatment is not likely to significantly impact the overall WTP mission duration or potential need for supplemental LAW treatment capacity.
2. Early initiation of LAW treatment will require design and implementation of interim pretreatment operations, either in-tank or near-tank, at the tank farm (see later sections of this report for more discussion). This may be considered advantageous for maturing technology to facilitate immediate and future processing flexibility, but it will have additional near-term costs.
3. Early initiation of LAW treatment will require development of a strategy for management of secondary waste (from scrubbing process gases and other operations). Primary radionuclides of concern with respect to secondary waste are ⁹⁹Tc and ¹²⁹I. The overall strategy for management of secondary waste includes on-site disposal in the IDF. However, treatment technology and requirements prior to disposal need to be determined and they depend on completion of a performance assessment for the disposal facility, which proceeds after the Environmental Impact Statement currently in development.
4. WTP facility modifications will be necessary. ORP has requested BNI to prepare a conceptual design report to evaluate the technical approach, schedule, and cost associated with the commissioning of the LAW facility after estimated construction completion in about 2012.²⁷ Technical considerations noted by ORP in the tasking letter included acceptance criteria for LAW delivered from the tank farms, requirements for management of the liquid effluents from the Analytical Laboratory and LAW facilities, additional piping and interconnections, and any required changes to the WTP Authorization Basis. BNI is scheduled to complete this analysis by November 2008.²⁸
5. Operating costs will be incurred earlier than currently planned for supporting tank farm retrievals in support of LAW treatment. Preliminary ORP estimates suggest that these earlier incurred operating costs will add about \$15 million in annual retrieval costs from 2010 through 2019.²⁹ However, this additional effort will likely accelerate the maturation of retrieval technology and help to more quickly reduce retrieval rate uncertainty.

²⁷ Letter 08-WTP-037, Thomas M. Williams (ORP) to Ms. N.F. Grover (BNI); "Contract No. DE-AC27-01RV14136, Preparation of a Cost and Schedule Estimate for Installing the Third Melter in the Low-Activity Waste (LAW) Vitrification Facility," dated February 13, 2008.

²⁸ "Safety considerations" should be addressed by BNI as they evaluate Authorization Basis changes.

²⁹ It is our understanding that BNI provided ORP with an updated estimate of the additional operating costs (and other tank farm-related costs) in early June 2008.

6. It may distract management attention and divert resources from completion of the balance of the WTP facilities.

6.5 INTERIM AND SUPPLEMENTAL PRETREATMENT NEEDS AND OPTIONS

TECHNOLOGY OPTIONS FOR PROVIDING INTERIM AND SUPPLEMENTAL PRETREATMENT

Cesium-137 removal from tank wastes is necessary to meet LAW requirements to be compatible with design of radiation shielding in subsequent processing at the LAW facility or supplemental treatment and for handling and subsequent disposal of the LAW.

There are several options for interim and supplemental pretreatment of tank wastes to remove cesium. The current IPS project options include cesium separation by fractional crystallization, “caustic-side” solvent extraction, and sorption on a solid sorbent. (Fractional crystallization also reduces the amount of sodium hydroxide needed to be added to solubilize aluminum). The wastes to be treated require separation of suspended solids from the caustic solutions containing ^{137}Cs prior to cesium separation. Separation of suspended solids is also necessary to remove precipitated actinides and strontium from low activity waste feed. (See the discussion of Sr and Actinide separation below).

Solids separation potentially can be carried out in-tank that is with processing equipment located within a tank riser, using rotary microfiltration. Alternatively, solids separation can be carried out in a separate facility using cross-flow filtration, the same technology planned for use in WTP Pretreatment. Enough development has been carried out on rotary microfiltration to establish its viability for solid separation in the current application. However, rotary microfiltration is not a well-established process commercially and therefore its use for tank wastes represents a risk for equipment availability and reliability.

Two types of ion exchange resins are under consideration for cesium removal: crystalline silico-titanate (CST), a non-elutable solid sorbent; and resorcinol formaldehyde (RF), an elutable resin. Fractional crystallization entails precipitation of sodium nitrate during evaporation using the tank farm evaporator. Both caustic-side solvent extraction and ion exchange systems can be deployed as near-tank, small-scale processes. Ion-exchange systems, which are designed to be deployed in a tank riser, also are under development.

Considerable work has been done at the Savannah River Site (SRS)^{30,31} and ORNL on in-tank pretreatment. Two approaches to pretreatment by placing processing equipment in tank risers have been examined in detail at SRS recently: (i) ^{137}Cs removal process by irreversible sorption on inorganic CST, and (ii) ^{137}Cs removal process by reversible sorption on RF organic ion exchange resin.

Operating processes in tank risers requires operator interaction. Unlike the use of permanently installed ion exchange equipment to remove cesium in the WTP pretreatment plant, the in-tank

³⁰ “Liquid Waste Operations: Enhanced Processes for Radionuclide Removal, Systems Engineering Evaluation,” G-ADS-H-00014, Revision 0, December 18, 2007.

³¹ Renee Spires, “Small Column Ion Exchange Processing for Salt,” LWO Technology Development, SRNL, April 7, 2008.

risers and their auxiliary equipment must be moved from tank to tank. This introduces the potential for operator exposure to both radiological and toxic chemical hazards.

Transfers of material to and from the waste tanks require on-site facilities to handle, treat, store, and dispose of the materials. Those materials include new and used RF, fresh CST, caustic to treat the resin before use and acid to elute ^{137}Cs from loaded resin if RF is used. The average column throughput is six - ten gpm. In both processes ^{137}Cs is to be removed until the effluent from the columns reaches 45 nCi/g. The NRC Class C concentration limit is 4600 Ci/m³. Consequently, as far as ^{137}Cs is concerned, the effluent is suitable for disposal by shallow land burial. Although removal of cesium by installing tank risers employing ion exchange or sorption on solids is not in the current IPS project, the concept has a great deal of merit and deserves additional consideration. This process is discussed below in greater detail.

Solids Separation

Two devices have been considered for solids removal: (i) a cross-flow filter and (ii) a rotary microfilter (manufactured by Spin Tek). The cross-flow filter is the more mature technology, so using it would be the more conservative approach. However, the rotary microfilter has been extensively tested with solids suspensions simulating tank waste and with waste tank sludge,³² and is faster than cross-flow filtration. Table 4 compares some important attributes of cross-flow and rotary microfilters, while Table 5 shows the results obtained with the rotary microfilter.

Table 4. Comparison of Cross-Flow and Rotary Microfilters

Attribute	Cross-flow	Rotary microfilter
Filter flux/size	Relatively lower flux and larger size than rotary microfilter	3 to 5 times larger filter flux than cross flow; smaller footprint
Ease of filter cleaning	Back-pulse system and chemical cleaning	Only chemical cleaning
Installation	IPS installed in process building rather than in DST riser due to equipment size	25 disk unit can be installed in 39 inch diameter DST riser
Maintainability	Large filter tube bundle and large capacity re-circulating pump; shielded capsule needed for filter bundle replacement	Small filter stack and small capacity pumps; can be remotely replaced similar to existing tank farm pumps
Operating experience	HLW slurry filtration at WVNS, Melton Valley, SRS, and Sellafield (UK); solids generally less than 5 wt%; planned for use at Hanford WTP at up to 20 wt% solids	Radioactive liquid waste treatment facility at LANL; concentrates to a 30wt% solids slurry

³² D.T. Herman, M.R. Poirer and S.D. Fink, "Testing and Evaluation of the Modified Design of the 25-Disk Rotary Microfilter," WSRC-STI-2006-00073, Revision 6, August 2006.

Table 5. Preliminary Rotary Microfilter Test Results
(25-disk unit; 0.5 micron pore size; tank AN-105 simulant)

Steady-state filter flux		
0.6 wt% solids	0.29 wt% solids	1.29 wt% solids
0.25 gal/min per disk	0.16 gal/min per disk	0.1 gal/min per disk

Fractional Crystallization

Fractional crystallization by evaporation of water is a promising approach for cesium separation from LAW in addition to partial removal of sodium in the form of sodium nitrate from the tank liquid wastes. Current maturity and applicability of this process for both cesium and sodium separations was discussed in the section entitled *Options for Reducing the Amount of Na to be Treated*.

Modular Caustic Side Solvent Extraction Unit

A mobile Modular Caustic Side Solvent Extraction Unit (MCU) is to be employed at SRS to remove ^{137}Cs from caustic waste solutions³³ with sodium concentrations of 3.6 to 7.0 molar. The solvent extraction process was developed at ORNL. The DOE Operational Readiness Review is complete and start-up of the unit has been accomplished. The MCU uses a specially engineered liquid organic extractant for cesium removal. Centrifugal contactors are employed for mixing and separating the organic and aqueous liquid phases because the contactors are both compact and fast. The average throughput of the MCU is four gpm (one million gallons per year).

The MCU ^{137}Cs decontamination factor (DF) is greater than 12, and in simulant tests was in the 100 to 500 range. The ^{137}Cs was concentrated 12 to 15 fold in the process. The separated cesium contained actinides and ^{90}Sr at levels low enough to meet regulatory Class C requirements. Organic phase carryover into the aqueous phase was less than 50 ppm. This is important because of the high cost of the organic extractant. Chemical, thermal and radiolytic stability of the extractant are good. Potassium competes with cesium in cesium removal operations. Because some Hanford tank wastes are higher in potassium content this fact must be taken into account when considering solvent loading and the effect of potassium on the cesium DF.

Construction of a full-scale solvent extraction process facility based on solvent extraction of ^{137}Cs by a process closely related to the MCU process, the Salt Waste Processing Facility (SWPF), will be begin at SRS starting in 2008 and is scheduled for operation in 2012.

³³ Renee Spires, "ARP/MCU Processing," LWO Technology Development, April 8, 2008.

Research is continuing at ORNL to find improved extractants.³⁴ The primary goals of the research are to find an improved solvent that has a higher solubility in the CSSX solvent, thus reducing the risk of precipitation, and greater resistance to third phase formation.

Cesium-137 Separation

A general discussion of the proposed ORP interim pretreatment system project has been provided.³⁵ There are several ways to provide supplemental pretreatment to remove ¹³⁷Cs from alkaline tank wastes. These include (i) build a stand-alone pretreatment facility, (ii) provide a modular pretreatment facility at a tank farm, and (iii) provide in-tank pretreatment. This section discusses the third option: in-tank pretreatment.

Considerable work has been done at SRS^{36, 37} and ORNL on in-tank pretreatment. Two approaches to in-tank pretreatment have been examined in detail at SRS recently: (i) ¹³⁷Cs removal process by irreversible sorption on inorganic crystalline silico-titanate (CST), and (ii) ¹³⁷Cs removal process by reversible sorption on resorcinol formaldehyde (RF) ion exchange resin.

Crystalline Silico-titanate Process

CSTs³⁸ are 70 to 90 percent silico-titanate with the balance being zirconium oxide and water. IONSIV IE-911 is a granular CST commercially available through UOP. It is generally spherical in shape with particle diameters ranging from 326 to 344 microns. A possible pathway for disposing of IE-911 loaded with cesium is by grinding it and dumping it into a tank (grinding is required prior to vitrification). However, there is a small tendency for IE-911 to clump and agglomerate, which could make its removal from a tank difficult. The cesium capacity of CST decreases with increasing pH, with the capacity decreasing by more than an order of magnitude when the pH increases from seven to ten. In addition, higher temperatures lower the equilibrium loading of cesium on CST, with a 26 percent decrease as the temperature is increased from 25 to 45°C. There is some formation of fines of IE-911, but the fines can be washed out easily.

In the CST process, one or more vertical cylindrical columns of the inorganic CST sorbent and a sorbent grinder are placed in “risers” in waste tanks. The function of the CST sorbent columns is to selectively and irreversibly remove soluble ¹³⁷Cs from the alkaline waste solution, which is filtered and pumped through the columns. The function of the sorbent grinder is to reduce the size of the CST particles after they have been loaded with ¹³⁷Cs prior to returning them to a waste tank where they are mixed with the sludge in the tank. The sludge containing the ground

³⁴ B.A. Moyer, L.H. Delmau and J.F. Birdwell, “The Caustic Side Solvent Extraction Process for Cesium Removal from Alkaline HLW: Improvements and Extension to Hanford Wastes,” EM-21 Review Meeting, Oak Ridge National Laboratory, April 22, 2008.

³⁵ Ben Harp, “Proposed Office of River Protection Interim Pretreatment System Project Critical Decision – 0,” Federal Project Director, November 20 2007 (pre-EMAAB).

³⁶ “Liquid Waste Operations: Enhanced Processes for Radionuclide Removal, Systems Engineering Evaluation,” G-ADS-H-00014, Revision 0, December 18, 2007.

³⁷ Renee Spires, “Small Column Ion Exchange Processing for Salt,” LWO Technology Development, SRNL+-, April 7, 2008.

³⁸ William D. King, “Literature Reviews to Support Ion Exchange Technology Selection for Modular Salt Processing,” WSRC-STI-2007-00609, November 2007.

CST loaded with ^{137}Cs (as well Cr, Fe, and small amounts of fission products and actinides) is then fed to the HLW vitrifier. Addition of CST to the sludge increases its volume and the volume of glass produced in the HLW vitrifier; the primary impact is due to the increased titanium concentration in the waste to be vitrified. The number of HLW waste product canisters is thereby increased. CST processing produces two primary waste streams: loaded CST and the decontaminated waste salt solution.

Resorcinol Formaldehyde Process

SuperLig 644 was the reference resin for the cesium ion exchange process system in the Hanford Tank Waste and Immobilization plant (WTP). Bechtel National, Inc. requested ORP approval of spherical RF ion exchange resin as the alternative to SuperLig 644 and submitted a document³⁹ based on experiments in support of its recommendation.

RF resin reacts with dissolved oxygen in both acids and caustic; the dry resin reacts with air. For this reason, RF resin is generally stored in the hydrogen form under water in a sealed container with inert gas in the container head space. RF resin sorbs chromium and iron from caustic solutions (up to 2 mg Cr and 0.1 mg Fe per gram of RF resin in the hydrogen form). Chromium is not readily leached from the resin. Less than five percent of the chromium is removed from solution, but up to 85 percent remains on the resin after elution with 0.05 M nitric acid. Radiation doses up to 10 Mrad have minimal effect on removal of cesium by elution.

In the RF process, one or more vertical cylindrical columns of organic RF ion exchange resin are placed in risers in waste tanks. The function of the RF resin columns is to selectively and reversibly remove soluble ^{137}Cs from the alkaline waste solution, which is filtered and then pumped through the columns. The ^{137}Cs is eluted from the columns with dilute nitric acid and after addition of caustic the eluate joins the HLW stream going to the waste vitrifier. This results in essentially no increase in the number of HLW canisters. However, additional treatment of the nitric acid resin column eluate containing the ^{137}Cs is required before its addition to the HLW waste stream. This impacts the WTP flowsheet. Also, the organic resin degrades after multiple sorption per elution cycle and the degraded resin becomes a waste stream.⁴⁰ The resin is expected to be used until it is about 20 percent degraded. The elution and regeneration cycle is expected to take about 30 hours. Changing out degraded resin is estimated to take about one week. The RF process produces three primary waste streams: spent resin, decontaminated waste salt solution, and acidic cesium eluate.

Strontium/Actinide Separation

The WTP baseline for pretreating supernatant waste includes a precipitation step for removing ^{90}Sr and actinide isotopes. Laboratory test reported by SRNL and BNI have demonstrated the effectiveness of the selected precipitation process for meeting the removal specification.⁴¹ The process involves the addition of three molar strontium nitrate and 3.83 molar sodium

³⁹ M. Thorson, "Basis for Recommendation of Spherical Resorcinol Formaldehyde Resin as the Approved Equivalent to SuperLig 644," 24590-WTP-RPT-RT-06-001, Rev 0, November 14, 2006.

⁴⁰ Resin degradation was identified as a problem in CCN: 132846 "Comprehensive Review of the Hanford Waste Treatment Plant Flowsheet and Throughput," May 17, 2006. Subsequent modification of the resin shape from fragments to spheres was claimed to have solved the problem.

⁴¹ *Research and Technology Plan*, 24590-WTP-PL-RT-01-002. Rev.1, USDOE/ORP.

permanganate to produce 0.02 molar $\text{Sr}^{(2+)}$ and 0.02 molar $\text{MnO}^{(1+)}$ in solution in tanks AN-102 and AN-107. The permanganate ion is expected to be reduced to MnO_2 , which scavenges any soluble actinides not precipitated by the alkaline waste and to oxidize the insoluble $\text{Cr}^{(+3)}$ in the tank sludge to soluble $\text{CrO}_4^{(-1)}$, thus removing it from the solids going to the HLW vitrifier where it would have a deleterious effect. The specification for Sr and actinide concentrations in the LAW are 20 curies per cubic meter for Sr and 100 nanocuries per gram for actinides. Target decontamination levels have been established at 50 percent below the LAW levels, which requires 90.2 percent and 38.3 percent removal of Sr and actinides, respectively for tank AN-102, and 91.3 percent and 85 percent of Sr and actinides, respectively for tank AN-107. Mass balance calculations show that these levels have been exceeded, demonstrating that the pretreated supernatant can meet WTP specifications. Although the required precipitation cannot be carried out in tanks AN-102 and AN-107 because of dilutions require to produce 5.5 molar sodium in the tanks, it can be carried out in tank 241-AP-102 (AP-102) to which the supernatants can be transferred. This separation step also potentially can be carried out in the WTP pretreatment facilities.

6.6 OPTIONS FOR INCREASED WTP LAW MELTER CAPACITY

Many of the general facility sizing concepts for the WTP were developed by the Hanford TWRS Privatization contractor (BNFL)⁴² and subsequently passed on by ORP to the current WTP contractor (BNI).⁴³ This included the nominal sizing of the WTP pretreatment facility to support production of 60 MT per day of LAW glass. The nominal sizing of the LAW vitrification facility originally supported production of 30 MT per day of LAW glass and a second LAW vitrification facility was envisaged to make up the 30 MT per day balance; other options were subsequently considered under the “Supplemental Treatment” program. The initial LAW facility design included three LAW melters, each capable of producing 10 MT per day of LAW glass. Each melter had a melt pool surface area of 10 m^2 , giving a specific glass production rate of $1 \text{ MT}/(\text{m}^2 \cdot \text{day})$.⁴⁴ This specific glass production rate is considerably higher than that obtained at the West Valley Demonstration Project (WVDP; West Valley, NY) and the Defense Waste Processing Facility (DWPF; Savannah River Site) because of the use of active melt pool mixing (vs. thermal convection) in the WTP melters (using “bubbler” systems). The ability to achieve the required specific rate of $1 \text{ MT}/(\text{m}^2 \cdot \text{day})$ was demonstrated through extensive testing on the LAW pilot melter at one-third scale (3.3 m^2 melt surface area) and rates above $1.5 \text{ MT}/(\text{m}^2 \cdot \text{day})$ were achieved.⁴⁵ This increase in melter performance meant that three melters could support

⁴² DOE, TWRS Privatization contract, 1996.

⁴³ DOE, “Design, Construction, and Commissioning of the Hanford Tank Waste Treatment and Immobilization Plant,” Contract Number: DE-AC27-01RV14136, Office of River Protection, Richland, Washington, 2000.

⁴⁴ In joule-heated ceramic melters, waste and glass forming chemicals (or glass frit) are poured onto the surface of the molten pool of glass, where they form a floating mass referred to as a “cold cap.” Other things equal, the rate of conversion of feed material to glass is directly proportional to the contact area between the molten glass and the cold cap. The maximum contact area is simply the geometric surface area of the melt pool. Consequently, a rational basis for scaling the glass production rate of such melters is by the surface area of the melt pool, which leads to the specific glass production rate in terms of mass of glass produced per unit surface area per unit time.

⁴⁵ Duratek, Inc., LAW Pilot Melter Testing Summary Report, REP-PLT-027, RPP-WTP Rev 1, Sept. 16, 2005.

LAW glass production rates of 45 MT per day or that two melters could support the 30 MT per day requirement.

As part of the LAW pilot melter test program, data were collected on the heat load resulting from prototypically filled full-scale LAW containers.⁴⁶ Based on these data, BNI and ORP concluded that the LAW facility design could not support the heat load associated with the operation of three LAW melters without significant modifications.⁴⁷ This resulted in the 2002 decision to delete the third LAW melter line and move to the so-called “two-plus-two” configuration⁴⁷, which employs two LAW melters with specific glass production rates of 1.5 MT/(m²·day) to meet the 30 MT per day LAW requirement and two HLW melters (rather than the one that was originally planned in the BNI contract).⁴³ As design and construction has moved forward on this basis, facility support for the potential subsequent installation of a third LAW melter has been incomplete, as discussed below.

WTP 3RD LAW MELTER OPTION

The LAW facility includes space for a third vitrification line, including the melter and all associated process vessels and support systems. However, while the ability to install the third line has been retained (as required by the BNI contract and per agreement with the State), the difficulty of such a retrofit has increased significantly as construction has proceeded and particularly once the 28 foot deck was installed. Recently, BNI was tasked by ORP with evaluating the potential impacts of the addition of the third LAW melter line into the WTP LAW facility and the results from that study became available at the end of May 2008. Based on the results of that study and information provided to this team by ORP from previous evaluations, the principal challenges are thought to be the following:

- Heat load issues:
 - The heat load issues (primarily below the 21 foot level) that originally led to the deletion of the third melter line still remain.
 - It is estimated that a ~50 percent increase in HEPA filters and fan systems in the below 21 foot elevation C5 ventilation system would be required.
 - Increased chilled water and compressed air requirements with potential changes to the chiller compressor plant.
- Access to install required vessels:
 - Access hatches would need to be cut into the 28 foot deck in order to install melter process and off-gas vessels required on the 3 foot level. The potential alternative of bringing the vessels in through the melter cell would entail cutting load-bearing walls.

⁴⁶ Duratek, Inc., RPP Pilot Melter Prototypic LAW Container and HLW Canister Glass Fill Test Results Report, TRR-PLT-080, Rev. 0, April 27, 2004.

⁴⁷ DOE, “An Evaluation of the LAW Facility Capability to Support a Two-Melter Peak Production Rate of 45 MTG/day,” R.L. Clendenon, L.E. Demick, W.F. Hamel, L.K. Holton, and J.E. Orchard, D-03-DESIGN-003, Office of River Protection, Richland, Washington, August 2003.

- Corresponding access hatches would need to be cut into the roof and the 48 foot deck. Vessel installation through these hatches would require the use of a special long reach crane, which is not currently available, on-site.
- Concrete embeds:
 - Embeds required to support the third melter line were installed on and below the 21 foot level of the LAW facility, but not on any of the higher elevations. Retrofitting would require cutting into concrete to install the necessary embeds.

Installation of the third melter line would also require the addition, or modification, of the following:

- Pour cave liner plate, LAW container carousel, shield windows and doors, bogies for container transport, and pour cave container handling equipment
- Melter installation rails, melter, power supply, process and off-gas vessels, primary off-gas treatment system equipment, and glass former hopper
- Piping, electrical, instrumentation, pumps, and agitators
- Increased on-site power and increased capacity of the switchgear buildings
- Potential modifications to the WTP analytical laboratory (LAB) to support the increased throughput.

In its May 2008 study, BNI addressed the heat load issues associated with adding a third 15 MTG per day melter by installing a new Container Finishing Building immediately east of the LAW facility. The planned LAW finishing line equipment would be located (or relocated) to this new facility in order to resolve the HVAC challenges posed by the increased capacity. The BNI study notes that while this pre-conceptual design solution was the most practical in the time available for the study, other more cost effective solutions may well exist, such as upgrading the HVAC systems in the LAW facility. This study considered installation of the third melter either prior to hot operations of the LAW facility (“Option 1” with authorization in 2010) or afterward with physical work beginning in 2022 (“Option 2”). BNI developed schedules and rough order of magnitude (ROM) cost estimates for each of these options. Its results are summarized below:

- Option 1: Add third 15 MTG per day melter with 2010 authorization
 - Approximately \$750 million
 - Earliest LAW facility hot operations would be 2018
 - Early LAW is not possible
 - Requires all three facilities be commissioned simultaneously
 - Requires controlled cessation of LAW and portions of BOF construction
 - Significant skill craft mix mobilization/de-mobilization.
- Option 2: Add third 15 MTG per day melter with physical work starting in 2022
 - Approximately \$1.25 billion
 - Requires three-year outage for LAW and significant portions of BOF

- Outage could extend to HLW and pretreatment; the cost impact for this extension is not included.

The outage required in Option 2 and its attendant impacts, as well as the uncertainty in the length of this outage and the higher ROM cost, makes this significantly less attractive than Option 1. In Section 6.12, the cost estimates from the BNI study for Option 1 are used to compare this option with other possible scenarios for increased LAW capacity.

TWO ENHANCED WTP LAW MELTERS OPTION

Independently of the BNI contract, ORP has supported the development of a variety of potential performance enhancements to the WTP LAW vitrification facility, including glass formulation development to increase waste loadings, along with melter design and operational enhancements to increase LAW glass throughput. A study performed for ORP in 2003 by the WTP melter designer identified three areas that could provide significant increases in melter throughput:⁴⁸

1. Data from nearly five years of one-third scale LAW Pilot Melter testing on 14 different WTP waste compositions showed that the average specific glass production rate was 2.05 MT/(m²·day), an increase of 37 percent over the 1.5 MT/(m²·day) requirement.
2. Data from one-third scale LAW Pilot Melter testing at modestly higher operating temperatures (1175 – 1225°C vs. the WTP nominal of 1150°C) resulted in specific glass production rates of up to 3.4 MT/(m²·day), a 126 percent increase over the 1.5 MT/(m²·day) requirement.
3. Modification of the internal design of the LAW melter, with no impact on the external features, could provide an increase in the melt pool surface area from 10 m² to 14.75 m². This increase is possible through more efficient internal space utilization in the locally shielded LAW melter coupled with reduced conservatism in the refractory design based on the experience gained from nearly five years of LAW pilot melter operations. However, the other facility systems (e.g., electrical, structural, HVAC) must also be compatible with the increased melter capacity.

These results suggest the following:

1. Data from large-scale testing indicate that the baseline LAW melter should be capable of meeting, and significantly exceeding, the specific glass production rate requirement of 1.5 MT/(m²·day), i.e., 30 MT per day for two WTP baseline 10 m² LAW melters.
2. Further increases in glass production rate may be available through modest increases in operating temperature. However, increased operating temperature will likely come with a cost in terms of reduced melter life (if the same materials of construction are assumed) and that trade-off would need to be better understood.
3. A second generation LAW melter could provide a significant increase in capacity while incurring minimal interface issues to the WTP facility since the external design is identical.

⁴⁸Duratek, Inc. "LAW Pilot Melter Decommissioning Project; Second Generation LAW Melter Conceptual Design Report," REP-LDD-001, Revision 0, Columbia, Maryland, December 2003.

The “Second Generation LAW Melter Conceptual Design Report”⁴⁸ provides considerable detail on the melter design changes and implications associated with increasing the melt surface area without impacting the external features of the melter. The report suggests the viability of such a design change to increase melter capacity. Accordingly, this approach may present a potential alternative to the installation of the third LAW melter line for increasing the WTP LAW vitrification capacity if the impacts of the higher capacity to the balance of the WTP LAW and BOF plants can be addressed. Replacement of the two baseline LAW melters by two second generation melters with increased melt surface area would achieve essentially the same increase in glass production rate as would installation of a third baseline melter.

BNI has been tasked by ORP with evaluating the potential impacts of the replacement of the two WTP LAW melters by two second generation melters, each with a 50 percent increase in throughput. The results from that study became available at the end of May 2008. Based on the results from that study and information provided to this team by ORP from previous evaluations, the principal challenges are thought to be the following:

- Heat load:
 - Essentially the same issue as for installation of the third melter
- Loading limits on the three foot deck:
 - The second generation melters would be intrinsically heavier and hold a larger mass of glass; this result needs to be evaluated but is a potential floor-loading issue
- Capacity of melter support systems:
 - The sub-systems in each melter line (such as feed preparation, glass former supply, power supply, cooling, off-gas, pour cave, container handling and decontamination, and export to DOE) need to be assessed with respect to its ability to support the increased throughput. ORP performed a parametric assessment of these systems in 2003.^{49, 50} This study concluded, based on the data available at the time, that the sub-systems could support the higher glass throughput rates produced by two 45 MT per day melters, with some utilization of ‘design margin’; the most limiting systems were associated with pour cave and finishing line cooling and glass canister handling. It would be beneficial to update the 2003 ORP parametric analysis using more recent information, including the results from the May 2008 BNI study.

Although many of the impacts on utility requirements (including ventilation, power, cooling, and compressed air) and analytical services are likely to be similar to those associated with installation of the third LAW melter, there are considerable differences with respect to the structural modifications and additional process equipment that would need to be installed.

⁴⁹DOE, “Design Oversight Report: LAW Melter Support Systems Capacities,” D-03-DESIGN-002, Office of River Protection, Richland, Washington, June 2003.

⁵⁰DOE, “An Evaluation of the LAW Facility Capability to Support a Two-Melter Peak Production Rate of 45 MTG/day,” R.L. Clendenon, L.E. Demick, W.F. Hamel, L.K. Holton, and J.E. Orchard, D-03-DESIGN-003, Office of River Protection, Richland, Washington, August 2003.

Unlike the third melter option, where an entire melter line would need to be retrofitted into a nearly completed facility, the option of employing two enhanced melters would entail replacement of the melter units by the planned routine replacement route (rails) and utilization of the two installed lines of melter support systems.

In its May 2008 study, BNI addressed the heat load issues associated with the installation of two higher capacity melters in the same way as for the third melter options, i.e., by adding a new container finishing building immediately east of the LAW facility into which the LAW finishing line equipment would be located (or relocated). The BNI study considered installation of the two upgraded 22.5 MTG per day melters either after the start of hot operations of the LAW facility (“Option 3”, with plant modification beginning in 2022) or prior to the start of hot operations (“Option 4” with authorization in 2010). BNI developed schedules and ROM cost estimates for each of these options; the results are summarized below:

- Option 3: Replace two 15 MTG per day melters with two 22.5 MTG per day melters with plant modifications starting in 2022:
 - Approximately \$1.17 billion
 - Requires three-year outage for LAW and significant portions of BOF
 - Outage could extend to HLW and pretreatment (the cost impact for this is not included)
 - Proof of viability of this concept requires significant detailed design to address shielding, local cooling in the pour caves, and potential structural issues associated with increased melter weight.
- Option 4: Replace two 15 MTG per day melters with two 22.5 MTG per day melters with authorization in 2010:
 - Approximately \$1.2 billion
 - Earliest LAW facility hot operations is 2020
 - Delays overall WTP facility completion by 27 months at an estimated cost of \$270 million, which is included; however, the cost of other possible programmatic impacts of this delay have not been evaluated and are not included
 - Early LAW is not possible
 - Proof of viability of this concept requires significant detailed design to address shielding, local cooling in the pour caves, and potential structural issues associated with increased melter weight.

The three-year outage required in Option 3 and its attendant impacts, as well as the uncertainty in the length of this outage, are clearly undesirable. The nature and extent of the modifications suggest that an outage of this general magnitude may be unavoidable. In contrast, while the 27-month WTP schedule delay in Option 4 would appear to be only marginally preferable; a review of the BNI schedule for Option 4 suggests that it may be possible to avoid this delay. The BNI schedule assumes that the melter capacity upgrades would be managed according to DOE Order 413.3, “Program and Project Management for the Acquisition of Capital Assets,” and therefore follow the sequential “Critical Decision” (CD) process. This assumption results in activities that could otherwise logically be run in parallel instead of in series, which results in an

extension of the schedule. In particular, the BNI schedule assumes that all LAW and BOF construction would be put on hold until final design for the upgrades and higher capacity melter was complete (CD-3), whereupon construction would resume. The applicability of DOE Order 413.3 to a direction change in an ongoing project is questionable. Removing this constraint has the potential to avoid the 27-month delay in Option 4 and would be a rational course of action. Accordingly, in analyzing potential scenarios to increase LAW capacity in Section 6.12, a modified Option 4 (“Option 4a”) is employed in which the 27-month delay and the associated \$270 million cost are deleted. The attributes associated with Option 4a inferred from the BNI study are expected to include the following:

- Option 4a: Replace two 15 MTG per day melter with two 22.5 MTG per day melter with authorization in 2010 (schedule assumed not subject to DOE Order 413.3):
 - Approximately \$930 million
 - Earliest LAW facility hot operations is 2018
 - Early LAW is not possible
 - Proof of viability of this concept requires significant detailed design to address shielding, local cooling in the pour caves, and potential structural issues associated with increased melter weight.

Under this option, the LAW facility would commence hot operations with the two upgraded (22.5 MTG per day) melter instead of the planned two 15 MTG per day melter, providing a total nominal capacity of 45 MTG per day. However, because of the time required to complete the facility modifications, Early LAW would not be possible.

In summary, there are a variety of means through which the WTP LAW vitrification capacity can be increased. They are currently limited more by the facility design, advanced state of construction, and installed melter support systems than by the capabilities of LAW melter technology.

6.7 BULK VITRIFICATION

As noted above, DOE has planned, since the inception of the WTP Project in the mid-1990s, to add additional LAW immobilization capacity. For that reason, DOE, Washington State Department of Ecology, and U.S. Environmental Protection Agency undertook in 2002 an evaluation of a wide range of potential LAW immobilization technologies as potential options to building a second WTP LAW facility. The agencies ultimately identified a second LAW facility, BV, CS, and SR facilities as the most viable options for supplementing the WTP LAW Vitrification Facility. Based on further evaluations, DOE elected to proceed with BV testing at the Hanford site, SR testing at its Idaho site, and CS (grout) testing at its SRS.

BV is essentially an “in-container” vitrification process, where the container in which the waste is vitrified is also used for final disposal; accordingly, the process is also referred to as In Container Vitrification (ICV). In this process, pretreated LAW material is mixed with glass forming chemicals, dried, and introduced into a refractory-lined steel container in batches. Graphite electrodes inserted through the lid of the container pass current through a conductive starter path on the floor, causing a layer of starter glass and initial waste batch to melt in order to initiate the glass melting process and joule heating. Batches of dried LAW material mixed with glass formers are then fed and vitrified until the container is filled. The molten glass is allowed

to cool and solidify, and the process is then repeated with a new container. A standard roll-off box sized steel container (24.0 ft x 7.6 ft x 7.6 ft) is used, which results in a glass mass of about 44 MT. The estimated cycle time for this essentially batch process is such that one BV line produces glass at about 5.24 MT per day, which at 70 percent availability yields 3.66 MT per day per BV line.

Considerable progress has been made in the development of BV technology through extensive research and development testing. However, the information that has been accumulated has shown that several of the perceived advantages that were the basis for the original selection of BV technology for further evaluation—such as lower cost, higher throughput, faster deployment, higher waste loadings, improved retention of technetium, increased tolerance to sulfur, and use of low-cost Hanford soil as a glass former—have not been demonstrated. Considerable progress has been made toward addressing the technical issues that have been identified through testing and by outside expert review teams^{51, 52}, but many significant challenges remain, as discussed below. In addressing these issues, the design has by necessity evolved from a simple facility assembled from low-cost, essentially “off-the-shelf” components, toward a much more realistic conventional nuclear waste treatment facility design. However, this evolution also has significantly increased cost, to the point that any cost advantage over other options has substantially narrowed.⁵³

The waste loading and sulfur tolerance advantages that are implied in the HTWOS modeling results in the System Plan⁵⁴ result from the use of an incomplete or outdated flowsheet assumptions for BV. The System Plan assumes that 99.7 percent of the sulfur that is fed to the BV system is driven off to the off-gas stream. It is therefore further assumed that there is no need for an upper limit on the acceptable concentration of sulfur in the BV feed in order to prevent molten salt formation because essentially all of the sulfur is driven to the off-gas stream. This assumption leads to a BV glass formulation model that assumes 21.24 wt percent Na₂O regardless of sulfur concentration. As a result, in contrast to the WTP, it is assumed that waste loadings are limited only by sodium and not by sulfur. However, these assumptions are inconsistent with the results from full-scale BV testing. In particular, data from the most recent full-scale BV test (FS-38D) shows that only 12 percent of the sulfur was driven to the off-gas stream.⁵⁵ This resulted in the formation of a significant molten sulfate salt phase in the waste package, despite the fact that the waste loading was lower than that assumed in the System Plan (17.7 wt percent vs. 21.24 wt percent Na₂O). Furthermore, analysis showed that about three percent of the rhenium (a surrogate for radioactive technetium) was contained in the highly

⁵¹ DOE, Technical Assessment of Bulk Vitrification Process/Product for Tank Waste Treatment at the Department of Energy Hanford Site, Washington, D.C., May 2006.

⁵² CH2M Hill, RPP-31314, Revision 0, A Comprehensive Technical Review of the Demonstration Bulk Vitrification System, September 2006.

⁵³ DOE/ORP-2007-03, Revision 0 Draft, “Hanford River Protection Project Low-Activity Waste Treatment: A Business Case Evaluation,” Office of River Protection, November 2007.

⁵⁴ CH2M Hill, ORP-11242, Revision 3, “River Protection Project System Plan,” P.J. Certa, et al., CH2M HILL Hanford Group, Inc. May, 2008.

⁵⁵ AMEC Nuclear Ltd., Demonstration Bulk Vitrification System Series 38 Full-Scale Testing, FS-38D, Test Report, 30686-RT-0003, Rev. 0, December 2007.

soluble salt phase. This finding represents a product performance risk that remains to be solved. Based on presently available data, the BV waste loadings assumed in the System Plan are optimistic, with the result that the BV facility sizes, associated capital and operating costs, and quantity of glass produced are underestimated.

In the opinion of this review team, the remaining technical risks associated with BV are greater than those associated with the WTP LAW flow-sheet. The WTP LAW flow-sheet is based on more conventional vitrification technology that is more thoroughly understood—as a result of DOE’s considerable investment in the base technology over several decades. Furthermore, there appear to be fewer remaining technical advantages and a cost advantage associated with BV that is less than previously estimated. Remaining advantages that have been cited include the following:

1. The ability to add BV line incrementally in a near tank configuration and to adjust the LAW treatment capacity over time.
2. The ability to handle LAW feeds with higher cesium content.

However, neither of these are advantages that are inherent in the BV technology; rather, they result from specific deployment and facility design decisions. Consequently, either of these features could possibly be achieved, if desired, with a WTP LAW flow-sheet, as discussed in Section 6.9.

Finally, it has been argued that use of a different LAW treatment technology from that employed at the WTP provides added “robustness.” While this could be true in a generic sense, it may not be accomplished by adding a higher risk treatment technology to the mix. Furthermore, the driver for this need is not apparent. From a vitrification perspective, pretreated LAW (a salt solution of relatively uniform composition) is considerably less chemically challenging than the HLW solids fraction of the tank waste, which span a wide range of compositions and waste-loading-limiting species; both the HLW and LAW streams are treated in the WTP using the same basic vitrification technology.

6.8 SECOND LAW FACILITY

One of the options for addressing the WTP LAW treatment capacity shortfall that DOE is considering is the deployment of a second LAW facility. In view of the extensive investment by DOE and others in the development of the underlying joule-heated ceramic melter technology in general and the thorough research and technology development program conducted to support the WTP LAW flow-sheet in particular, this option is considered to be the low-risk option for which the base technology is mature and well understood. In addition, in view of the advanced state of deployment of the first WTP LAW facility, the cost and schedule uncertainty and associated risks should be lower than for other potential alternatives. All of the enhancements that have been developed for potential use in the first LAW facility would be directly applicable to a second LAW facility and many would be easier to implement in a new-build situation (e.g., melter upgrades). These enhancements include increased waste loadings, as well as increased melter throughput using any combination of the methods described in Section 6.6. Assuming a similar three-line LAW facility and the potential for installing 15 MTG per day or 22.5 MTG per day melters in each line, the total nominal capacity for the second LAW facility could be 15.0, 22.5, 30.0, 37.5, 45.0, 52.5, 60.0, or 67.5 MTG per day; thus, there is considerable capacity flexibility associated with this option. Furthermore, it does not preclude early

operations of the first LAW facility (Early LAW). The time required to deploy this option would be compatible with a 2017 decision on supplemental treatment in order to bring that added capacity on-line by 2024.

Although the second LAW option would incur significant additional capital investment, comparable investments would be associated with many of the other options (e.g., melter upgrades or BV), as described in Section 6.12, where costs for a range of possible scenarios for increased LAW capacity are evaluated.

6.9 VARIANTS OF WTP LAW VITRIFICATION

The basic WTP flow-sheet and LAW vitrification technology are sufficiently well developed and flexible that it is worth considering variants. In particular, the same basic WTP LAW flow-sheet could be deployed to achieve modularity or the higher cesium loading if these were determined to be desirable.

There is no technology obstacle to deployment of the same WTP LAW flow-sheet in multiple lines with essentially any capacity per line that is desired. Plus, there are no intrinsic features of the base vitrification technology or flow-sheet that would prevent this deployment. Rather, extensive test data can support the viability of “scalable” line capacity from the two pilot melters that have been operated to support the WTP flow sheet. These systems have melter surface areas of 3.3 m² and 1.2 m², which at the baseline WTP specific throughput of 1.5 MT/(m²·day), would result in 5 MT glass per day per line and 1.8 MT glass per day per line, respectively. Similar melters with both larger (5 m²) and smaller (0.10 and 0.02 m²) capacities have also been extensively operated. Consequently, if modularity is judged to be desirable, there are WTP LAW-based routes to achieving it that may have lower technical risk than BV.

The ability to handle LAW feeds with higher cesium content accrues primarily from the self-shielding associated with the much larger BV container. In comparison, the smaller WTP LAW containers produce a higher dose rate for the same cesium concentration and mass of glass as a result of their greater surface area to volume ratio. It should be noted that this distinction is most relevant for container handling and not at the melter stage. Consequently, differences are due to the selection of the container size and the facility design. WTP LAW and WTP HLW, as well as DWPF and WVDP, use joule-heated-ceramic melter technology but each facility uses different container designs. Thus, the WTP LAW flow-sheet potentially could be deployed with a larger container, if sufficiently advantageous. However, since essentially all of the Hanford LAW material requires pretreatment to remove cesium prior to vitrification (either by WTP or BV), the ability to handle higher cesium feeds may impact the required extent of cesium removal, but not the need for some form of cesium removal process.

Such variants of the WTP LAW flow-sheet, if sufficiently advantageous, would require additional assessments. Conceptual design and trade-off analysis of using the WTP LAW flow-sheet with a facility configuration modified to be potentially better suited to meet the needs of additional LAW treatment capacity have not been carried out and would need to be considered.

6.10 TRU PROCESSING AND DISPOSITION

Processing of waste from several tanks that could be classified as TRU waste will require retrieval, dewatering, drying, and packaging for shipment and disposal at WIPP, Carlsbad, NM. Implementation of TRU disposal of Hanford TRU wastes requires a Record of Decision from the

Tank Waste Closure and Waste Management EIS; approval of a class three permit modification from the New Mexico Environmental Department (NMED) for the disposal of wastes previously managed as HLW (per DOE agreement); a RCRA permit for the treatment and packaging facilities at Hanford. Currently, disposition of TRU from ORP tank wastes is part of the System Plan, but not part of the WIPP inventory of TRU wastes to be disposed and therefore is not on the WIPP disposal schedule. Improved coordination between ORP and WIPP is needed to ensure that the TRU management schedule developed at ORP is consistent with the requirements, schedule for needed regulatory approvals, and the schedule for the WIPP facility to accept the waste.

6.11 ORP COST ESTIMATES

ANALYSIS OF THE COST ESTIMATES

The use of baseline cost estimates for planning purposes is reasonable and prudent. Those baseline estimates were last “validated” by an external review team in 2006.⁵⁶ To our knowledge, there are no validated cost estimates that are more current than these baseline estimates.

However, we have two concerns. Our primary concern is that the baseline cost estimates for the WTP operating costs are premised on a 2003 cost analysis.⁵⁷ While this cost analysis appears very competent, it was based on assumptions that are now more than five years old. Given the knowledge that has been gained over these past five years, plus recent revisions in the schedule and cost estimates for the Waste Treatment Plant Project, the relevance and validity of those underlying assumptions should be challenged. Tank Farm, feed delivery, supplemental treatment, and LAW disposal capital and operating costs are based on a bottom-up cost estimating process, which is based on historical tank farm data, and subject to validation.⁴²

Our other concern deals with the cost escalation rate assumption. The assumption of costs increasing, on average, at a rate of 2.4 percent per year is somewhat optimistic. Our review of historical costs for both construction and “general” expenses over the past 30 years suggests the following: on average, construction costs will increase at a rate of about 3.6 percent per year, and general costs will increase at about 3.5 percent per year.⁵⁸ By our calculations, there is only a 15 percent probability that inflation will be 2.4 percent or less in any particular year.

⁵⁶ Two reviews were conducted in 2006: an initial review of the performance baseline and a follow-up review to examine the revisions to the baseline estimates made in response to the initial review findings. See LMI, *Office of River Protection Tank Farm Project: External Independent Review*, Report DE635T1, A. Scott Dam, et al., September 25, 2006; and LMI, *Baseline Validation Recommendation*, Chris Gruber and Gerald W. Westerbeck, December 2006.

⁵⁷ Office of River Protection, *Assessment of Low-Activity Waste (LAW) Treatment and Disposal Scenarios for the River Protection Project (RPP)*, L.K. Holton, et al., April 14, 2003.

⁵⁸ For construction costs, we examined construction cost indexes from two sources highly regarded in the construction industry: Engineering News Record and Chemical Engineering Magazine. Engineering News Record compiles two indexes: the Construction Cost Index (CCI) and the Building Cost Index. Over the past 30 years, CCI costs have increased, on average, 3.62 percent (+ or - 0.75 percent); BCI costs, 3.84 percent (+ or -0.64 percent). The Chemical Engineering Magazine compiles the Chemical Engineering Plant Cost Index

In the short term (between now and 2012), an optimistic estimate of inflation may not have a significant effect on the current estimate. Yet, in the mid-term (seven or eight years out), if inflation increases, on average, at historic norms, it could add \$80 million to \$100 million to the total annual cost (assuming the current base cost estimates are accurate). By 2024, inflation could add \$150 million to \$200 million over the current annual cost estimate. This is a sufficient cost risk to prompt a re-examination of an appropriate escalation factor for use in subsequent cost estimates.

COST TRADE-OFFS BETWEEN LAW AND HLW TREATMENT

Pretreatment of the HLW feed to remove aluminum (through caustic leaching) is carried out to reduce the number of vitrified HLW canisters produced. Aluminum removed from the HLW is then treated as part of the LAW stream. The amount of LAW requiring treatment is greatly increased as a consequence of the large sodium additions required to achieve the needed extent of aluminum removal. The net effect is considered beneficial because of the lower unit cost of handling and on-site disposal of treated LAW compared to interim storage and off-site disposal of HLW. However, an updated life-cycle trade-off analysis, based on current data, of the relative costs of LAW treatment and disposal and HLW treatment and disposal has not been performed. Such a life-cycle cost analysis would be useful in determining the appropriate balance for future investments in LAW treatment capacity and management costs versus incurring the production of additional HLW canisters because of lower waste loading as a result of increased aluminum content in the waste feed.

6.12 COMPARATIVE SCHEDULE AND FINANCIAL ANALYSIS OF SELECTED SCENARIOS BY REVIEW TEAM

We examined four broad scenarios (or courses of action) to address the LAW treatment needs. Each scenario had at least one variation. These scenarios are not intended to include all of the potential variations, but rather to examine the financial and schedule implications of several potential decisions presently being evaluated. These scenarios are summarized in Table 6. Important underlying assumptions in the scenarios analyzed are as follows:

1. For the 60,000 MT Na cases, the average sodium oxide (Na_2O) loading in vitrified LAW for all cases is assumed to be 19 wt percent, except the Present RPP System Plan variants (2a, 2b, 2c). This loading is based on recent studies for LAW glass formulation in combination with a variety HTWOS modeling runs performed for this study by ORP. The loading is somewhat greater than the average WTP LAW loading that was assumed for the Business Case WTP scenarios, which was about 17.6 wt percent. The average sodium loading for the Present RPP System Plan variants (2a, 2b, 2c) was 19.6 wt percent, per the System Plan. This overall average loading results from an average loading of 18 wt percent Na_2O for the WTP and 21.24 wt percent for BV on using the

(CEPCI). Over the past 30 years, CEPCI costs have increased 3.3 percent (+ or - 0.67 percent). Projections, using time series statistical forecasting models, suggest that construction cost will continue to increase on an average annual rate in the 3.5 percent to 3.7 percent range. Similar analysis of general inflation, based on historical data from the Gross Domestic Product Implicit Price Deflator over the past 30 years, suggest similar trends.

current BV glass formulation model, the latter of which we believe will be a challenge to achieve because of observed sulfur phase separations during recent test programs, as discussed in Section 6.7. For the 90,000 MT Na cases, HTWOS modeling leads to slightly higher loadings (e.g., 21.7 vs. 19.0) as a result of the dilution of sulfate by the additional sodium (i.e., a reduction in the sulfate to sodium ratio in the waste).

2. A minimum operating interval for WTP of 30 years due to retrieval limitations is assumed, to provide consistency with present targets for completion by 2049 and the RPP System Plan. This assumption also provides a more uniform basis for comparison of options. However, completion of the WTP mission in less than 30 years may be possible with improvements in waste retrieval efficiencies, as well as other system attributes (e.g., pretreatment, sodium reduction strategy, etc.).
3. All scenarios assume that the HLW treatment can be completed in 23 to 26 years (see Figure 4) and therefore HLW treatment is not limiting WTP mission completion.
4. For the 60,000 MT Na cases, the “not-retrieval-limited” curve from HTWOS modeling runs (Figure 4) was used to determine the treatment duration unless the duration fell below 30 years, whereupon it was set to 30 years. For the 90,000 MT Na cases, the mid-point duration between retrieval-limited and not-retrieval-limited curves was used to determine the treatment duration unless the duration fell below 30 years, whereupon it was set to 30 years.
5. Operating conditions and constraints for the Present RPP Plan variants (2a, 2b, and 2c) use the same assumptions as provided in the RPP System Plan.
6. Scenario variants that include Early LAW assume that Early LAW will operate for five years prior to full radioactive waste operations at WTP. This assumption was selected to determine the impact of Early LAW using the earliest possible start date for WTP LAW, even though it is subject to the schedule uncertainties discussed earlier (Section 5.5) and potentially may not be attainable. For the WTP with Early LAW (1b), Early LAW is assumed to reduce overall estimated mission completion date by five years, even though the mission duration is unchanged (WTP LAW operations are simply moved forward by five years). For the scenario where Early LAW is added on to the Present RPP Plan, two variants are examined: one where Early LAW results in WTP mission completion five years earlier (completion in 2044; Scenario 2b), and one where Early LAW does not realize the anticipated acceleration in completion date (completion in 2049; Scenario 2c). For Scenario 2b, although the completion date is accelerated to 2044, the overall duration of operations is reduced only by two and a half years because approximately half of the LAW would be processed through supplemental treatment capacity. Similarly, for the scenario of Second LAW with Early LAW (4b), the mission completion date is accelerated by five years relative to Second LAW (4a), but the mission duration is only reduced by two and a half years.
7. Scenario 4c assumes that the second LAW facility is an enhanced LAW facility (enhanced through means described in Sections 5.7 and 5.9) to increase the net processing capacity to the extent necessary to achieve the 2049 completion date (30-year mission duration).

We examined the scenarios using an economic analysis framework in order to assess the cost and schedule for each scenario. ORP provided the basic cost and schedule data for the scenarios in June and July of 2008 and reviewed this economic analysis for factual accuracy.

Because of the uncertainty associated with achieving the estimated costs, we created “uncertainty distributions” to reflect our understanding of the precision of the estimates. We used two primary sources to inform our approach to handling uncertainty: the 2007 LAW Business Case Evaluation, which contained ORP’s expert judgments about the precision of estimates for alternatives similar to those that we considered; and industry standards⁵⁹ for order of magnitude and semi-detailed levels of accuracy estimates—the levels of accuracy in the ORP June and July estimates. We adjusted the cost data (the density functions) to reflect our estimate for cost escalation over the analysis period.⁶⁰ Then, so we could make meaningful comparisons among

⁵⁹ We referred to sources for guidance on applying uncertainty ranges to the cost estimates: the American National Standards Institute’s Standard Reference Z94.2; and the Association for the Advancement for Cost Engineering International’s Recommended Practice No. 18R-97. For order of magnitude level of accuracy estimates, such as for new construction and decommissioning and demolishing facilities, we typically considered distributions that ranged from the cost estimate, itself, to as much as 50 percent over the estimate. For routine operations, our distributions ranged from 5 percent below the cost estimate to 120 percent above the estimate. For other activities, the distributions ranged from the estimate to 120 or 130 percent above—depending on the activity.

⁶⁰ We assumed that costs would increase, on average, 3.5 percent per year (+ or - 0.3 percent). This rate reflects the average annual inflation over the past 40 years, as measured by the Gross Domestic Product Implicit Price Deflator—the Government’s broadest index to inflation (Federal Reserve Bank of St. Louis, Economic Research, <https://research.stlouis.org/useraccount/datalists/9559/download>, accessed June 10, 2008). It is one of the indexes suggested for use in Government cost effectiveness analyses in OMB Circular A-94 (January 2008).

Table 6. The Four Scenarios

Scenario	Assumed average Na ₂ O loading*	Facility on-line date					Completion date (WTP mission duration)	
		IPS	Supplemental LAW	Early LAW	Upgraded WTP LAW	Total nominal capacity	60,000 MT Na	90,000 MT Na
1a. WTP only	19 wt%	No	No	No	No	30 MTG/d (21 net)	2073 (54 yrs)	2093 (74 yrs)
1b. WTP only with Early LAW	19 wt%	2014	No	2014	No	30 MTG/d (21 net)	2068 (54 yrs)	2088 (74 yrs)
2a. Present RPP System Plan (SP3)	21.24 wt% for BV 18 wt% for WTP	2014	DVBS: 2011 BVS: 2013 STE = 4-line BV: 2019 STW = 4-line BV: 2014 Total nominal capacity (STE + STW): 42 MT G/d	No	No	72 MTG/d (50.4 net)	2049 (30 yrs. limited by retrieval)	2055 (36 yrs)
2b. Present RPP System Plan with Early LAW (2046)	21.24 wt% for BV 18 wt% for WTP	2014	DVBS: 2011 BVS: 2013 STE = 4-line BV: 2019 STW = 4-line BV: 2014 Total nominal capacity (STE + STW): 42 MT G/d	2014	No	72 MTG/d (50.4 net)	2046 (32 yrs.)	2052 (38 yrs)
2c. Present RPP System Plan with Early LAW (2049)	21.24 wt% for BV 18 wt% for WTP	2014	DVBS: 2011 BVS: 2013 STE = 4-line BV: 2019 STW = 4-line BV: 2014 Total nominal capacity (STE + STW): 42 MT G/d	2014	No	72 MTG/d (50.4 net)	2049 (35 yrs. limited by retrieval)	2055 (41 yrs)
3a. Enhanced WTP (3 rd melter)	19 wt%	No	No	No	2019 Nominal capacity: 45 MTG/d	45 MTG/d (31.5 net)	2055 (36 yrs)	2070 (51 yrs)

Scenario	Assumed average Na ₂ O loading*	Facility on-line date					Completion date (WTP mission duration)	
		IPS	Supplemental LAW	Early LAW	Upgraded WTP LAW	Total nominal capacity	60,000 MT Na	90,000 MT Na
3b. Enhanced WTP (two 22.5 MT melters)	19 wt%	No	No	No	2019 Nominal capacity: 45 MTG/d	45 MTG/d (31.5 net)	2055 (36 yrs)	2070 (51 yrs)
4a. Second LAW	19 wt%	No	2024 Nominal Capacity: 45 MTG/d	No	No	75 MTG/d (52.5 net)	2049 (30 yrs limited by retrieval)	2054 (35 yrs)
4b. Second LAW with Early LAW	19 wt%	No	2024 Nominal Capacity: 45 MTG/d	2014	No	75 MTG/d (52.5 net)	2046 (32 yrs)	2051 (37 yrs)
4c. Enhanced Second LAW	19 wt%	No	2024 Nominal Capacity: 52.5 MTG/d	No	No	82.5 MTG/d (57.8 net)	2049 (30 yrs limited by retrieval)	2049 (30 yrs limited by retrieval)

* Na₂O loadings are listed for the 60,000 MT Na case; these loadings increase slightly for the 90,000 MT case due to the dilution of sulfate.

Note: DBVS = Demonstration Bulk Vitrification System; BVS = Bulk Vitrification System; BV = Bulk Vitrification; STE = Supplemental treatment in the east tank farm area; STW = Supplemental treatment in the west tank farm area; and MTG/d = Metric tons of glass per day.

the scenarios, we converted the set of expected future cash flows for each scenario to a corresponding present worth measure.⁶¹

We examined the present worth in terms of both point and interval estimates (using probability density functions). We evaluated those estimates through statistical hypothesis testing, assessing whether the present worth distributions of the scenarios (and their variants) were substantially different from each other.⁶² Our criterion was to identify, from the government's perspective, the course of action with the most favorable present worth of expected future costs that completed waste treatment by 2049—the presently estimated completion date. We present our findings below, starting with the estimates under the 60,000 MT Na assumption and we follow that subsection with our findings under the 90,000 MT Na assumption. A set of overall observations follows.

THE 60,000 MT SODIUM ASSUMPTION

In Table 7, we present the results of our calculations of the point estimates for each of the scenarios under the 60,000 MT Na assumption. This table also shows the associated WTP mission durations and completion dates.

In Table 8, we present our calculations of the interval estimates for the present worth of the expected future costs. These intervals are the 90 percent Bayesian credible intervals derived from Monte Carlo simulations. The interpretation of these credible intervals is that, for each scenario, we are 90 percent confident that the true present worth value is contained within the range of credible values of the defined interval. For instance, for Scenario 1a, WTP Only, we believe that there is a 90 percent probability that the true present worth of the future costs associated with this scenario is contained in the range \$25.4 billion to \$34.0 billion.

Figure 5 provides a graphical depiction of the interval estimates.

⁶¹ The present worth expresses the value today of a set of future cash flows, discounted to reflect the time value of money. The Government's time value of money, as prescribed in Appendix C of OMB Circular A-94 (January 2008), is 4.9 percent per year.

⁶² We applied Bayesian one-sided hypothesis tests. First, we ranked the cost distributions by their mean values, starting with the least cost present worth. Our null hypothesis was that the mean value of the lower cost alternative was different from the mean value of the next ranking alternative. To test this hypothesis, we determined the ratio of the probability of not exceeding the mean present worth value of lower cost alternative to the probability of not exceeding that same present worth value in the next ranking alternative. We then inferred the strength of evidence to support the null hypothesis. If the ratio was greater than 1 but less than 2, we inferred that the difference between the means was not worth mentioning. If the ratio ranged between 2 and 3, the strength of evidence was moderate. If the ratio ranged between 3 and 10, the evidence was substantial. If the ratio ranged between 10 and 30, the evidence was strong. If the ratio was 30 to 100, the evidence was very strong. A ratio greater than 100 suggested decisive evidence. For example, if the probability is 0.52 that the mean present worth value of Alternative A will not exceed \$25 and the probability is 0.12 that Alternative B will not exceed that same present worth value, \$25, then we would infer that there is substantial evidence to support a null hypothesis that Alternative A has a lower present worth than Alternative B.

Table 7. Estimate: Present Worth of Expected Future Costs
with Associated WTP Mission Durations and Completion Dates
(60,000 MT Na Assumption)

Scenario	Present worth of expected future costs (\$ billions)		WTP mission duration (years)	Completion date
	Mean	Standard deviation		
1a. WTP Only	29.3	2.8	54	2073
1b. WTP with Early LAW	29.3	2.5	54	2068
2a. Present RPP Plan	27.1	1.7	30	2049
2b. Present RPP Plan with Early LAW (2046)	27.0	1.5	32	2046
2c. Present RPP Plan with Early LAW (2049)	28.2	1.8	35	2049
3a. Enhanced WTP (3 rd melter)	25.9	1.9	36	2055
3b. Enhanced WTP (two 22.5 MT melters)	26.1	2.0	36	2055
4a. Second LAW	25.0	1.7	30	2049
4b. Second LAW with Early LAW	24.9	1.5	32	2046
4c. Enhanced Second LAW	26.4	1.8	30	2049

Table 8. Interval Estimates of the Present Worth of Expected Future Costs
(60,000 MT Na Assumption)

Scenario	Present worth of expected future costs (\$ billions)	
	5 th percentile	95 th percentile
1a. WTP Only	25.4	34.0
1b. WTP with Early LAW	25.4	33.7
2a. Present RPP Plan	24.4	31.0
2b. Present RPP Plan with Early LAW (2046)	24.5	28.4
2c. Present RPP Plan with Early LAW (2049)	25.4	29.3
3a. Enhanced WTP (3 rd melter)	22.8	29.4
3b. Enhanced WTP (two 22.5 MT melters)	23.0	29.4
4a. Second LAW	22.4	27.7
4b. Second LAW with Early LAW	22.6	27.5
4c. Enhanced Second LAW	23.5	29.5

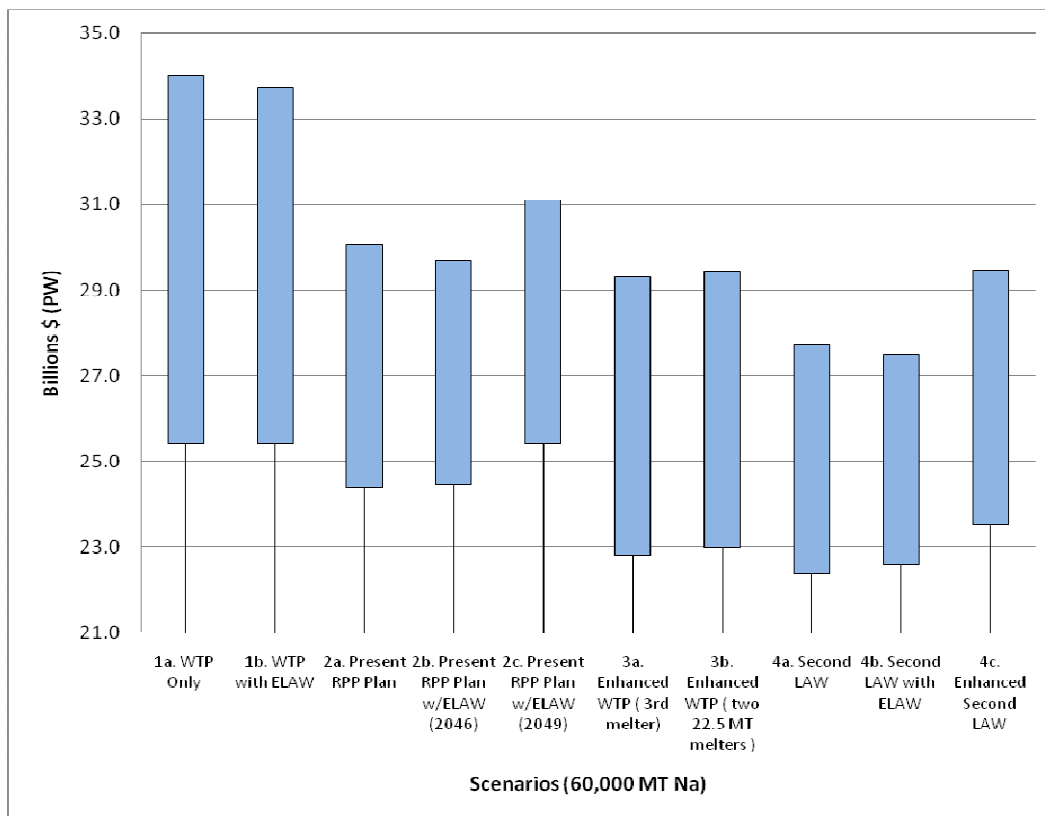


Figure 5. Interval Estimates of the Present Worth of the Expected Future Costs; 90 Percent Credibility Interval (60,000 MT Na Assumption)

Our statistical hypothesis testing of these estimates suggests that we can arrange the scenarios in two broad groups, one with a more favorable present worth and another with a less favorable present worth:

- The group with the more favorable present worth values comprises the Enhanced WTP and Second LAW variants (Scenarios 3 and 4). The differences between the present worth distributions for these two scenarios are insubstantial from a statistical perspective.
- The group with the less favorable present worth values comprises the Present RPP System Plan and WTP Only variants (Scenarios 1 and 2). The differences between their present worth distributions are also insubstantial.

These results also suggest that only the variants of the Present RPP System Plan and Second LAW scenarios will complete waste treatment on or before 2049. The Enhanced WTP variants have completion dates of 2055—only 6 years beyond the desired end date. The WTP Only variants will complete treatment much later: the basic WTP Only scenario in 2073 and the variant with early LAW in 2068. The mean values of the present worth of the expected future costs range from a low of \$25 billion for Second LAW and Second LAW with Early LAW to a high of \$29 billion for the WTP Only variants.

THE 90,000 MT Na ASSUMPTION

Table 9 shows our point estimates, subject to a 90,000 MT Na assumption. It, too, contains WTP mission duration and completion dates for each scenario. With one exception, costs are higher and completion dates are later for all alternatives, as compared to the alternatives under the 60,000 MT Na assumption. The exception is Enhanced Second LAW (Scenario 4c). This scenario is very similar in terms of costs and duration to the corresponding scenario under the 60,000 MT Na assumption. We have assumed that the Enhanced Second LAW facility will be sufficiently sized to give ORP the flexibility to accommodate a wide range of sodium loading constraints, up to and including the 90,000 MT Na case, and still meet the desired 2049 completion date. For this case, we assumed that the marginal annual operating costs increase by about 20 percent over the corresponding operating costs under the 60,000 MT Na assumption (due largely to factors such as the costs of LAW containers and glass forming chemicals, which scale with the amount of glass produced rather than the operating duration).

The RPP Plan variants and the other two Second LAW variants will likely come close to meeting the desired 2049 completion date—all within 6 years after 2049.

However, the WTP Only variants have such long expected duration times that they put at risk the viability of the WTP, which has a nominal design life of 40 years. After more than 70 years of operation, the WTP facility will likely have exceeded its useful service life and require extensive on-going repair and rehabilitation measures to keep it operating—if not replacement. In addition, SST integrity risks increase as the treatment duration increases and for the scenarios with the longest durations, even DST integrity would need to be considered.

Table 9. Estimate: Present Worth of Expected Future Costs
with Associated WTP Mission Duration and Completion Dates
(90,000 MT Na Assumption)

Scenario	Cost (present worth in billions)		WTP mission duration (years)	Completion date
	Mean	Standard deviation		
1a. WTP Only	34.0	3.9	74	2093
1b. WTP with Early LAW	33.8	3.5	74	2088
2a. Present RPP Plan	29.8	2.1	36	2055
2b. Present RPP Plan with Early LAW (2046)	29.7	2.0	38	2052
2c. Present RPP Plan with Early LAW (2049)	30.8	2.1	41	2055
3a. Enhanced WTP (3 rd melter)	31.2	2.9	51	2070
3b. Enhanced WTP (two 22.5 MT melters)	31.5	2.9	51	2070
4a. Second LAW	27.5	2.0	35	2054
4b. Second LAW with Early LAW	27.8	1.8	37	2051
4c. Enhanced Second LAW	26.7	1.9	30	2049

Table 10 presents the 5th and 95th percentile values of the 90 percent credibility interval estimates, while Figure 6 illustrates the interval estimates under the 90,000 MT Na assumption. The ranges represent the 90-percent credible interval for each scenario.

Table 10. Interval Estimates of the Present Worth of Expected Future Costs
The 5th and 95th Percentiles of the 90 Percent Credibility Interval (90,000 MT Na Assumption)

Scenario	Cost (present worth in billions)	
	5 th percentile	95 th percentile
1a. WTP Only	28.2	40.8
1b. WTP with Early LAW	29.7	42.5
2a. Present RPP Plan	26.4	33.4
2b. Present RPP Plan with Early LAW (2046)	26.5	33.1
2c. Present RPP Plan with Early LAW (2049)	27.5	34.5
3a. Enhanced WTP (3 rd melter)	27.1	36.1
3b. Enhanced WTP (two 22.5 MT melters)	27.1	36.7
4a. Second LAW	24.4	30.9
4b. Second LAW with Early LAW	25.9	33.7
4c. Enhanced Second LAW	23.5	29.5

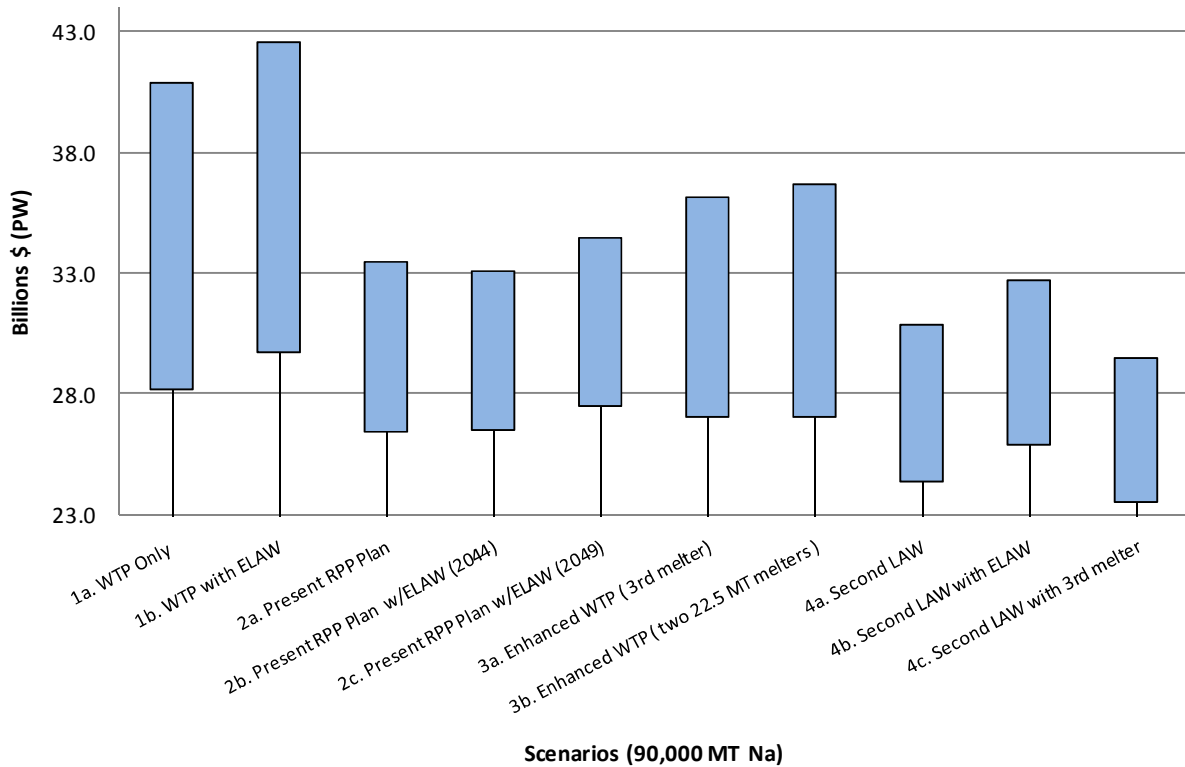


Figure 6. Interval Estimates of the Present Worth of the Expected Future Costs: 90 Percent Credibility Interval (90,000 MT Na Assumption)

Our statistical hypothesis testing of these estimates suggests that we can arrange the scenarios in three broad groups: one with a more favorable present worth, one with a less favorable present worth, and one with the least favorable present worth, as shown below:

- The group with the more favorable present worth values comprises the Second LAW variants.
- The middle group comprises the RPP System Plan variants and the Enhanced WTP variants.
- The group with the least favorable present worth values comprises the WTP Only variants.

Each of the scenarios requires implementation of a different sequence of capital and operating expenses for either facility enhancements or new facilities, and therefore has different cost-time profiles which are contained in the present worth analyses. For example, the current RPP System Plan includes design and construction of interim pretreatment facilities, modifications to WTP to facilitate Early LAW, and construction of BV facilities to provide supplemental treatment. This approach increases costs in the very near-term. Adding additional melter capacity to the LAW vitrification facility under construction also adds additional costs in the very near-term to avoid delaying construction completion beyond 2019. Implementation of a second LAW facility incurs design costs prior to 2017 and new facility construction costs between 2017 and approximately 2024. Detailed analysis of the cost factors and time sequence of costs for each scenario, along with uncertainty analysis, was provided separately.

OBSERVATIONS

Based on the forgoing analysis of the estimated present worth of the scenarios investigated, the mission completion dates, and, in particular, the ability to meet the presently estimated 2049 completion date, we can make several observations. ORP is presently evaluating the total amount of sodium to be treated in the WTP, which is currently estimated to go as high as 90,000 MT. For this assumption, the Enhanced Second LAW option (Scenario 4c) is the most favorable option. Scenario 4c meets the 2049 estimated completion date and has the lowest present worth. The other two Second LAW scenarios (4a and 4b) are also attractive by these measures, but they do not meet the 2049 end date. The realized total amount of sodium to be treated will depend on the effectiveness of the sodium mitigation efforts, which is subject to significant uncertainty at this time. Thus, Scenario 4c provides a hedge against the risk that these measures are less effective or less economically attractive than desired, such that the realized sodium inventory is closer to the upper end of the expected 60,000 to 90,000 MT range. For the 60,000 MT Na case, the Second LAW variants (Scenarios 4a, 4b, and 4c) and the Enhanced WTP variants (Scenarios 3a and 3b) have the most desirable present worth, but only the former group meet the 2049 estimated completion date (however, the Enhanced WTP variants produce an estimated duration of 36 years versus the 30-year duration of the 2049 estimate).

Overall, this economic analysis indicates that the Scenario 4 variants, in general, and Scenario 4c, in particular, appear to provide the best alternatives, if the estimated completion date of 2049 is held constant. However, a flexible estimated completion date has the potential to bring into consideration the “Enhanced WTP” cases, Scenario 3, for the 60,000 MT assumption. The capacity and deployment flexibility that is possible with the Scenario 4 variants is an additional consideration, in view of the uncertainty in the total amount of sodium that will require treatment. Other features of this scenario include the potential for lower cost, and schedule and technical risks that result from the information and experience gained from the development, design, and construction of the present WTP LAW facility. In addition, there are a variety of technical, programmatic, and intangible factors that should be considered in the decision-making process (see Sections 6.5, 6.7, 6.8, and 6.9), and we consider them to be particularly relevant for the various Early LAW scenarios.

7.0 CONCLUSIONS AND RECOMMENDED PRIORITIES

The results of this evaluation indicate that a decision on how to proceed, including the technical approach, with providing supplemental LAW treatment capacity is not needed until 2017. The amount of supplemental LAW treatment capacity needed is highly uncertain, primarily because it depends on several program aspects that currently are highly uncertain, including the amount of sodium to be treated with LAW and the rate of waste retrievals from presumed leaky single shell tanks. Reducing key program uncertainties requires urgent attention to be prepared for the proposed 2017 decision schedule. A second LAW vitrification facility would provide extensive flexibility in the additional treatment capacity to be constructed, depending on the number and capacity of melters and supporting systems included, and appears most favorable from a financial perspective. A second LAW facility would also permit attainment of WTP mission completion by 2049 for the currently considered full potential range of sodium requiring treatment (60,000 to 90,000 MT Na). Enhancements to the present LAW facility would provide a potentially viable option under the assumption of 60,000 MT Na, if there is flexibility to go to a 36-year WTP mission.

A comparative schedule and cost analysis was carried out for four broad scenarios (or courses of action) to address LAW treatment needs. Each scenario was evaluated under assumptions of 60,000 and 90,000 MT sodium to be treated. In addition, a minimum mission duration of 30 years was assumed to facilitate comparison with the present RPP plan; however, shorter mission durations may be possible with improvements in efficiency to waste retrievals and operations than currently assumed. The scenarios and variants evaluated are listed below (and described fully in Section 6.11):

- 1a. WTP only
- 1b. WTP with Early LAW
- 2a. Present RPP Plan
- 2b. Present RPP Plan with Early LAW (mission completion in 2046 for 60,000 MT Na)
- 2c. Present RPP Plan with Early LAW (mission completion in 2049 for 60,000 MT Na)
- 3a. Enhanced WTP (3rd LAW melter)
- 3b. Enhanced WTP (two 22.5 MT/day melters)
- 4a. Second LAW
- 4b. Second LAW with Early LAW
- 4c. Enhanced Second LAW

WTP mission duration, completion date and life-cycle present worth were modeled. This analysis indicates the following:

1. A second LAW vitrification facility (Second LAW and Enhanced Second LAW) would provide the most favorable present worth, while making possible attainment of the presently estimated 2049 mission completion date for the full range of potential sodium quantities to be treated. This result is possible because of the flexibility in sizing the capacity of a second LAW vitrification facility and that the selection and capacity sizing

decision would not be required until 2017, allowing time to reduce key program uncertainties.

2. Inclusion of Early LAW with any of the base scenarios (WTP Only, Present RPP system Plan, or Second LAW) results in an insignificant reduction in life-cycle present worth. However, non-financial benefits derived from Early LAW also warrant consideration.
3. If schedule flexibility exists, enhancements to the present LAW facility would result in a six-year mission extension beyond the current system plan completion date of 2049 and provide a favorable present worth under the assumption of 60,000 MT Na.
4. Each of the scenarios requires implementation of a different sequence of capital and operating expenses for either facility enhancements or new facilities, and therefore has different cost-time profiles, which are contained in the present worth analyses.

For the ORP path forward to address the disposition of LAW, the review team recommends the following list of priorities. These priorities are based on our current understanding of schedule and technical constraints. As indicated above, there are many uncertainties that can impact the overall needs and progress of the program, so periodic reviews of these priorities should be considered as new information becomes available.

High Priority

1. **Complete WTP by 2019; ensure timely feed delivery.** Completing WTP construction and initiating waste processing operations by 2019 should be the program's highest priority. Waste retrieval and transfer limitations may potentially extend mission duration. We believe that infrastructure upgrades and waste retrieval system improvements essential for providing feed to the WTP have too low visibility and priority. We recommend establishing a separate project comprised of the elements that are essential for meeting feed delivery expectations. In addition, waste retrievals from the SSTs required by the TPA should be used as a foundation for improving waste retrieval efficiency. *This priority is urgent and requires ongoing attention.*
2. **Develop and implement a sodium management strategy.** Reducing the quantity of sodium in LAW to be vitrified, and the associated uncertainty in this quantity, is the most important element in determining the duration, need for additional LAW treatment capacity, and cost of the mission. Sodium is the primary constituent in vitrified LAW that limits waste loading and thereby determines the quantity of vitrified LAW to be produced; other constituents present in the waste, such as sulfur, may further limit waste loading in vitrified LAW. Sodium, which is already present in the waste, is also added during pretreatment of HLW as part of aluminum and chromium extraction from HLW to reduce the vitrified HLW production.⁶³ Uncertainty in both the waste composition currently stored in the HLW tanks and the amount of sodium required to be added during HLW pretreatment render highly uncertain the estimate of the actual sodium quantity to

⁶³ The program considers the disposition of vitrified HLW in an off-site national geologic repository to be far more expensive than on-site disposal of vitrified LAW, so it seeks to minimize the quantity of vitrified HLW produced.

be treated.⁶⁴ The current estimates of sodium quantity appear to be biased (high) as a result of limitations in thermodynamic models, uncertainty in the amount of free hydroxide ion in the current inventory, and margins used for sizing process equipment.⁶⁵ Several potential process modifications also may reduce the amount of sodium to be treated and the vitrification capacity required to treat the final amount of sodium. Resolution is needed prior to 2017 for the approaches to optimizing sodium management, along with the amount and approach to additional LAW treatment capacity, for timely construction of additional processing facilities, if needed. Some options may have long development and demonstration lead times or be limited or eliminated by progression of WTP construction. Development and implementation of an integrated strategy to address sodium management and future LAW treatment capacity requirements is in its infancy and urgently needed. The scope of the sodium management plan should include quantification of the uncertainty and bias in current sodium estimates; uncertainty reduction strategies and tracking of uncertainty reductions; improved thermodynamic and kinetic models for key process steps, especially aluminate solution stability, and evaluation, including demonstration when promising, of process modifications that reduce the amount of sodium to be treated and the needed LAW vitrification capacity. *This priority is urgent.*

3. **Improve integrated system modeling capability.** A complete, consistent, and integrated model of tank farm, retrievals, operations, and WTP system performance is essential for program management, providing a basis for schedules, cost estimates, and evaluation of “what if?” scenarios. The resulting model should be an accurate reflection of the current understanding of the entire system and include uncertainty evaluations, formal optimization techniques, and updating strategies. The user interface should facilitate rapid modification and documentation of model run assumptions and parameters. Management and implementation strategies should be modified to facilitate much more extensive and near real-time use of the model as a system planning and evaluation tool. An independent review with appropriate expertise that is specifically focused on the model implementation and use is recommended. *This priority requires ongoing attention.*

Medium Priority

4. **Reduce uncertainty in supplemental treatment capacity needs (requires items 2 and 3, above).** Components to reducing uncertainty in the amount of sodium to be processed should include (a) evaluation of potential flowsheet modifications to reduce sodium additions during processing, (b) laboratory and bench-scale testing for process and thermodynamic and kinetic model development, and (c) engineering-scale process

⁶⁴ Uncertainties in waste inventory with respect to sulfur, aluminum speciation, chromium, sodium, and other constituents impact the uncertainty in the amount of sodium to be treated. The amount of sodium hydroxide to be added during pretreatment under the current process plan also is highly uncertain.

⁶⁵ Bias is introduced into estimates when a safety margin, or “conservativeness,” is applied (appropriately) for specific design purposes, but then the resulting estimates are used for other purposes (e.g., program planning) without recognition of the inherent bias or uncertainty in the estimates.

demonstrations. Pretreatment engineering-scale platform Phase II testing, employing a wider range of simulants and process conditions, will be important to reducing uncertainty related to WTP pretreatment operation. Additionally, strategies that further reduce the needed LAW vitrification capacity, beyond sodium use reduction, should be evaluated, including (a) use of fractional crystallization to separate sodium, sulfate (to improve sodium loading in LAW glass), and reduce ^{99}Tc in LAW, and (b) development of an improved performance assessment for the on-site disposal of treated LAW. The impact of these strategies on waste forms needs to be included as part of the evaluation process. Support should also continue for improved glass formulations that allow increased waste loadings for both HLW and LAW. *This priority, after implementation of Priority 2, is urgent and requires ongoing attention.*

5. Evaluate WTP LAW upgrades that provide for future capacity enhancement.

Preliminary evaluation suggests the capacity of the WTP LAW facility may be significantly increased in the future if physical modifications to balance of plant facilities (such as electrical supply and cooling capacity) are made prior to construction completion. Specifically, providing increased system capacity now that would allow upgrades in individual melter capacity from 15 MT glass per day to 22.5 MT glass per day with either two or three melters during planned melter replacements may be practical and financially attractive, and not delay overall WTP construction completion. However, WTP LAW upgrades may put completion of WTP LAW on the critical path for overall WTP construction completion. Evaluation of these options will also provide insights into potential design improvements for a second LAW facility if selected. However, for modifications to the LAW facility currently under construction, impact to the current skilled labor employed at WTP construction and vendors also should be considered. The additional capital cost of LAW upgrades to allow future installation of two enhanced melters is approximately \$930 million during the 2010 to 2019 timeframe. *A decision of whether to proceed with WTP LAW upgrades is urgent, to avoid extension of WTP completion, if this option is selected.*

6. Enhance support for focused technology demonstration. The Office of Engineering and Technology (EM-20) and field technology demonstration programs provide early support for technology maturation that must be completed prior to technology adoption as part of program plans. Insufficient support for this program prevents timely availability of some promising approaches (because of insufficient remaining lead time for needed maturation) and increases programmatic risk for other approaches due to only limited testing. Sufficient support should be made available for approaches that improve waste retrieval efficiency, augment the sodium and aluminum management strategy, improve system modeling capabilities, and reduce the need for supplemental treatment capacity (Priorities 1, 2, 4 and 5). Support is also needed for evaluation of cementitious and other low-temperature treatments for secondary wastes. The current program clearly has benefitted from earlier technology demonstration investments, such as in rotary microfiltration, waste retrieval technology, fractional crystallization, waste loading improvements, and melter capacity enhancements. *This priority is an ongoing need.*

7. Refine TRU strategy. Improved coordination will be needed between the ORP and WIPP programs to establish the schedule, define requirements, and obtain needed

approvals for disposition of TRU tank waste at WIPP. Currently, disposal of TRU waste from ORP is not part of the TRU waste management plan for WIPP. *This priority requires attention to ensure schedule compatibility between ORP and WIPP plans.*

- 8. Planning for Early LAW and supporting systems.** The primary benefits of Early LAW are (a) demonstrated progress in LAW treatment (assuming operations from 2014 to 2019, free up DST space, and retrieve 5 to 10 additional SSTs); and (b) staggering the start up, and associated staffing and training, of the major WTP facilities. (The planned rapid change in staff requirements and training associated with WTP start up is a concern and additional options to alleviate this potential bottleneck should be explored.)

Total additional cost for Early LAW is estimated at \$300 million for capital expenses and \$1 billion for operating expenses from FY 2009 through 2019. Results of this evaluation indicate that reduction in life-cycle costs is not sufficient to justify proceeding with Early LAW, but the decision also should consider the associated non-financial benefits.

Early operation of LAW requires additional WTP modifications, interim pretreatment, and a strategy for interim management of secondary waste. Estimates provided to the team indicate that interim pretreatment requires a four- to seven-year lead time for new facility construction, and development of a secondary waste management strategy is in very early stages. Thus, the current schedule for required system functionality to support early LAW may not allow a 2014 start and potentially may not allow a sufficient operating window to be justified. Early LAW also would preclude WTP LAW upgrades (Priority 5). This analysis is based on currently available information and assumptions and did not include review of the new Tank Operations Contractor (TOC) proposal. The relative benefit and priority of Early LAW should be re-evaluated if either (a) WTP LAW upgrades (Priority 5) are found to be impractical based on more detailed evaluation, (b) WTP construction completion is delayed beyond 2019, or (c) the schedule and costs associated with supporting systems necessary for Early LAW are substantially reduced. *A decision of whether to proceed with Early LAW is urgent.*

Low Priority

- 9. Planning and development for BV.** BV is an “in-container” vitrification process, where the container in which the waste is vitrified is also used for final disposal. Considerable progress has been made in the development of BV technology through extensive research and development testing. As testing on this technology and design of a demonstration system have progressed, there appear to be fewer advantages of this technology over other potential supplemental treatment alternatives than previously thought. In view of the need date for supplemental treatment down-selection (about 2017), along with the current uncertainties in sodium inventory and in the requirements for additional LAW treatment capacity—coupled with the advanced level of our understanding of this technology—further development work on BV should not be a high priority. Testing results have indicated that waste loading to avoid phase separation of sulfur and the distribution of technetium within the treated waste and the off-gas treatment system remain as critical issues. *Further testing of bulk vitrification is not urgent.*

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APPENDIX A – BIOGRAPHIES OF REVIEW TEAM MEMBERS

David S. Kosson. Dr. Kosson is Professor and Chair of the Department of Civil and Environmental Engineering at Vanderbilt University, where he also has joint appointments as Professor of Chemical Engineering and Professor of Earth and Environmental Sciences. He also is co-principal investigator (with Charles Powers) of the multi-university Consortium for Risk Evaluation with Stakeholder Evaluation. Professor Kosson's research focuses on management of nuclear and chemical wastes, including process development and contaminant mass transfer applied to groundwater, soil, sediment, and waste systems. His research on leaching of contaminants from wastes and construction materials is currently providing the foundation for environmental regulation of these materials at U.S. EPA, the Netherlands Ministry of Environment and the European Union's Directorate General for the Environment. Professor Kosson also has provided expertise and leadership for the National Academies, and as advisor to the Department of Defense, for more than a decade on demilitarization of chemical weapons in the United States and abroad. Professor Kosson has authored more than 100 peer-reviewed professional journal articles, book, book chapters and other archival publications. He received his Ph.D. in Chemical and Biochemical Engineering from Rutgers University, where he subsequently was Professor of Chemical and Biochemical Engineering.

David R. Gallay. Dr. Gallay has more than 30 years of experience as an engineering manager and research analyst. Currently, as the program director of LMI's Infrastructure and Engineering Management practice, he provides research and analysis services to public-sector clients in areas involving public works-related program and project management, engineering economics and finance, and cost uncertainty analysis. Among his projects for the Department of Energy, Dr. Gallay has managed the economic and financial analyses of four business case studies that examined the alternatives to restructure the National Nuclear Security Administration's complex of nuclear laboratories and nuclear material storage locations throughout the United States. He has led independent assessments of business case analyses advocating the acquisition and operations of office buildings, multi-purpose laboratory facilities, and other infrastructure through private sector financing, instead of conventional line-item federal budgeting, at or near five Department of Energy installations. He has also been asked repeatedly by senior management at the Department of Energy to serve on teams of outside experts to review, from both an economic and technical perspective, the Department's plans for investments in capital infrastructure to carry out high-cost initiatives, such as the disposal of the national stocks of surplus plutonium and uranium. In addition to his affiliation with LMI, Dr. Gallay is an adjunct faculty member at The George Washington University, where he teaches courses in finance and engineering economics. Before joining LMI, he was a career Army officer who served in military engineer and operations research positions. He holds a bachelor of science in engineering from the U.S. Military Academy, a master of science in civil engineering from Purdue University, a master of science in systems management from the University of Southern California, and a doctorate in engineering management from The George Washington University. He is a registered professional engineer and a certified cost engineer.

Ian L. Pegg. Dr. Pegg is Professor of Physics and Director of the Vitreous State Laboratory at The Catholic University of America where he manages and directs a staff that has reached 110 scientists, engineers, and technicians working in a variety of basic and applied research and development areas. Dr. Pegg has led numerous vitrification R&D programs involving the development and characterization of glass formulations and the demonstration and scale-up of Joule-heated melting processes. His research interests include the materials science and structure of glasses, optimization of glass compositions for use in nuclear waste disposal, leaching mechanisms and the chemical durability of glasses, high-temperature properties of glass melts, and high-temperature materials interactions with glass melts, as well as the thermodynamics of the bulk and interfacial properties of multi-component fluid mixtures. Dr. Pegg teaches undergraduate and graduate courses in physics and has directed Ph.D dissertations in both physics and chemistry. Dr. Pegg's publications include over 140 papers, several patents, and over 300 peer-reviewed technical reports. He is a member of the board of directors of ZT3 Technologies, Inc. He holds a Ph.D in physical chemistry (University of Sheffield, United Kingdom, 1982) as well as an MBA and B.Sc.

Raymond G. Wymer. Dr. Wymer is former Director of the Chemical Technology Division of ORNL and is now a consultant for the laboratory, the U.S. DOE, and its various contractors on all aspects of the nuclear fuel cycle and radioactive waste management. He has served on a United Nations Special Commission to Iraq and consulted with the U.S. Department of State on nuclear nonproliferation matters. Dr. Wymer is a specialist in radiochemical separations technology for radioactive waste management, nuclear fuel reprocessing, and uranium isotope separation by chemical exchange. He is a past member and is currently a consultant to the Advisory Committee on Nuclear Waste for the U.S. Nuclear Regulatory Commission. He is a fellow of the American Nuclear Society and the American Institute of Chemists. Dr. Wymer has been honored with the American Institute of Chemical Engineers' Robert E. Wilson Award in Nuclear Chemical Engineering and the American Nuclear Society's Special Award for Outstanding Work on the Nuclear Fuel Cycle. He received a B.A. from Memphis State University and an M.A. and Ph.D. from Vanderbilt University.

Steven L. Krahn. Dr. Krahn is the Director of the Office of Waste Processing, Office of Engineering and Technology, within DOE-EM; this office targets engineering and technology investments to identify, advance, develop, and implement engineering concepts, technologies, and practices that improve the performance of DOE cleanup projects and provides interdisciplinary engineering consultation, guidance, expertise, and continuity to DOE-EM. Prior to rejoining the government in 2007, Dr. Krahn spent 30 years in technical and project management positions of increasing responsibility in government, private industry and the military, including: the management of the \$140 million complex overhaul of a nuclear submarine; technical direction of the research and development program for a major DOE reactor program; providing technical direction and leadership for a federal agency providing safety oversight to the U.S. nuclear weapons complex; directing a \$25 million division in an engineering services company; and providing technical consulting services to the U.S. nuclear industry. He holds a BS in Metallurgical Engineering from the University of Wisconsin, a MS in Materials Science from the University of Virginia, a Doctorate in Public Administration from the University of Southern California, and is a graduate of the Bettis Reactor Engineering School (U.S. DOE).

APPENDIX B – EXTERNAL TECHNICAL REVIEW CHARTER

CHARTER

Evaluation of Alternative Supplemental Treatment of Low-Activity Waste at Hanford

1.0 Background

The DOE Hanford site near Richland, Washington, stores approximately 53 million gallons of chemically hazardous and radioactive wastes in 177 underground tanks, 149 SST and 28 DST. The storage of waste in the SSTs poses greater environmental risks than storage of wastes in DSTs, which are newer and have a second shell to mitigate leakage. Sixty-seven of the SSTs previously leaked as much as one million gallons of tank waste into the soil surrounding the Hanford tanks; this leakage has increased risk to the Hanford area groundwater and the Columbia River. As a result, DOE has removed pumpable liquids from the SSTs to mitigate the threat of additional leakage during waste storage. Leakage risks increase and are carefully managed when DOE adds liquids to SSTs to retrieve wastes from those tanks.

The 28 DSTs have inadequate capacity to receive all of the SST wastes. Additional DST space will be created as waste is withdrawn from the DSTs for treatment in the WTP, which will enable additional SST wastes to be retrieved. The Department estimates that it can achieve, on average, one SST retrieval each year (primarily sludge tanks from C-Farm) between now and the time the WTP is scheduled to commence hot operations in 2019. Until that time, the rate of SST retrievals will continue to be constrained by the availability of DST space. This is illustrated in Figure ES-1.

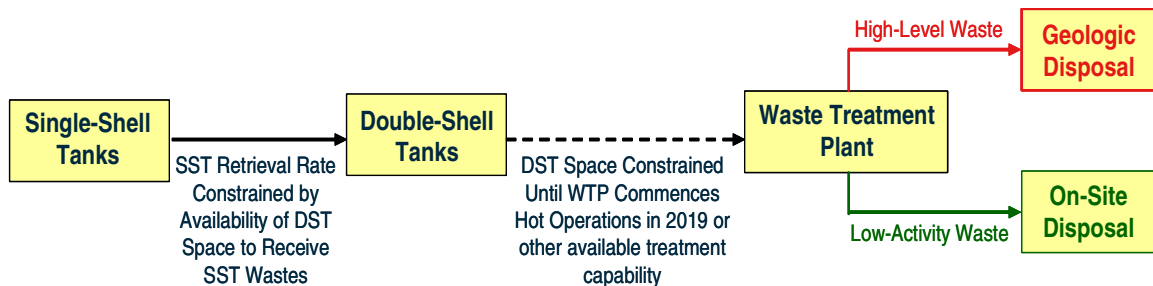


Figure 1. Until WTP Startup, DST Space Will Constrain SST Retrieval Rate

Most of the Hanford tank wastes resulted from spent nuclear fuel reprocessing (i.e., recovery of plutonium for defense purposes from spent nuclear fuel). The radioactive material content in the Hanford tanks, approximately 195 million curies including fission product daughter radionuclides, only makes up a few percent of the tank waste dry mass. Most of the dry tank waste mass consists of chemicals added to the wastes during reprocessing, during other Hanford operations, as well as for corrosion control. As a result, DOE has long planned to separate the chemical materials from the radioactive materials to the extent practical in order to minimize the mass of waste it disposes of in the Yucca Mountain HLW repository. The WTP PT Facility is designed to produce a HLW feed stream that contains over 95 percent of the radioactivity and a LAW feed stream that contains over 90 percent of the chemical dry waste mass. This is illustrated in Figure ES-2.

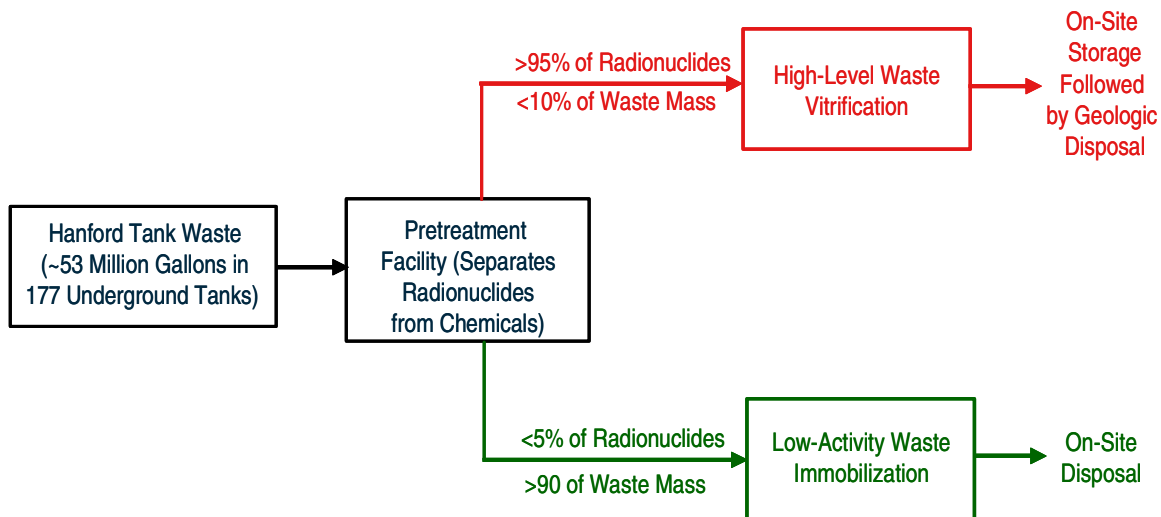


Figure 2. Simplified Hanford Tank Waste Treatment and Immobilization Flow Diagram

The pretreated HLW feed will be vitrified (transformed into glass) and stored on site until it can be disposed of in the proposed spent nuclear fuel and HLW repository at Yucca Mountain, Nevada. The pretreated LAW feed will also be immobilized but it will be disposed of on site. The LAW fraction that is immobilized by the WTP LAW Facility will be vitrified. The LAW fraction that is immobilized by a supplemental LAW immobilization technology, if any, could be vitrified or immobilized using alternative processes as discussed in this report.

The WTP HLW Facility is designed to vitrify all of the pretreated HLW feed over a 23- to 35-year period. Based on the WTP commencing hot (radioactive) operations in 2019 and the 27-year HLW pretreatment and immobilization mission duration in this study, HLW immobilization could be complete in 2046. The Department currently estimates that it will produce between 10,000 and 14,000 HLW canisters depending upon the effectiveness of its initiatives to increase waste loading in the glass. At approximately 3.2 MT of glass per canister, that translates into approximately 32,000 to 44,800 MT of HLW glass. For comparison, if DOE vitrified all Hanford LAW in the WTP LAW Vitrification Facility (as assumed in Business Case 1), DOE would produce approximately 400,000 MT of LAW glass; i.e., there would be approximately 10 times as much LAW glass as HLW glass.

The Department has planned since the inception of the WTP Project in the mid 1990s to add additional LAW immobilization capacity. For that reason, in 2002, DOE, the Washington State

Department of Ecology, and the U.S. Environmental Protection Agency undertook the evaluation of a wide range of potential LAW immobilization technologies as potential options to building a second WTP LAW facility. The agencies ultimately identified a second LAW facility, BV, CS, and SR facilities as the most viable options for supplementing the WTP LAW Vitrification Facility. The Hanford Tank Farm Contractor issued contracts to the BV, CS, and SR facility technology vendors to develop waste forms for DOE's consideration and to develop pre-conceptual designs to implement the supplemental immobilization technologies. Based on its evaluations of the vendors' submissions, DOE elected to proceed with BV testing at the Hanford site, SR testing at its Idaho site, and CS (grout) testing at its Savannah River Site.

The Department has not yet selected a definitive immobilization process to supplement its Hanford LAW Facility. The Department will make that decision in accordance with its project management orders and the *National Environmental Policy Act of 1969* (NEPA), pursuant to the *Tank Closure and Waste Management Environmental Impact Statement* (TC & WM EIS)⁶⁶.

2.0 Scope of the Review

This review will focus on three primary areas:

- Review the systems plans for Alternative Supplemental Treatment of LAW at Hanford, from retrieval to final disposition
- Review the ORP path forward for LAW disposition
- Provide a preliminary/qualitative evaluation of the issues and benefits associated with the potential installation of a 3rd LAW melter, based on the available information

3.0 Team Membership

The team will include five or more independent experts whose credentials and experience align with the specific lines of inquiry (LOI) listed below and who collectively provide to the team sufficiently broad capability and flexibility to address the full range of issues that may emerge in this review. Technical expertise includes, but is not limited to design, engineering and management of chemical processing and radioactive waste management systems. Individual expertise and experience will be commensurate with the LOI. The experts must be free of any conflicts of interests with Bechtel or CH2M HILL.

Each team member is responsible for conducting a thorough, professional and independent review, for supporting the identification and resolution of technical issues, for participating in the development of draft and final reports, and for supporting resolution of comments and any points of disagreement. Collectively, the team is responsible for producing a high quality review report that is responsive to this charter, that includes unambiguous conclusions regarding the identified lines of inquiry, and that presents clearly any dissenting viewpoints. All team members will sign the final report.

⁶⁶ 71 FR 5655, "Notice of Intent To Prepare the Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, WA," *Federal Register*, February 2, 2006.

Attachment 1 lists the team members for this review.

4.0 Period of Performance

This review will formally begin in late March 2008, although the collection of background information began in early March. The review shall include a combination of presentations, interviews with key personnel, information gathering sessions, independent document reviews, and group discussions. The review is expected to be completed at the end of April 2008. The key milestones for the review team are as follows:

- | | |
|---|---------------------|
| • Site Visit to Hanford | March 24 - 28, 2008 |
| • Status Briefing to EM Senior Management | April 11, 2008 |
| • Team Meeting – Draft Report | April 14 – 16, 2008 |
| • Final Report Approved by Team Members | April 23, 2008 |

5.0 Lines of Inquiry

Is there an adequate overarching strategy (master plan/schedule) developed to integrate all systems and operations under consideration that will be necessary for processing high-level tank waste at Hanford? A systems approach ensures that all operations and interfaces, risks and alternatives are evaluated to ensure that throughput, schedule and budget and other overall requirements are met. “Adequate” considers maturity of each aspect with respect to schedule; is the degree of development and planning sufficient to meet the schedule for implementation? What aspects of a systems approach are in place, and which aspects are missing?

- Is the overall mass balance and throughput consistent with mission requirements, and are mass and energy balances consistent between operations and interfaces for all options and combinations under consideration?
- Are LAW processing requirements projected for options under consideration including additional sodium separations, early LAW scenario, 3rd LAW melter scenario, sodium recycle, aluminum removal, various supplemental treatment technologies and all combinations that are under consideration? (For example, if early LAW was implemented and sodium recycle incorporated, what capacity requirements then exist for BV, which tanks would be treated, and what equipment cost would be incurred? If this analysis has not occurred, is it scheduled to occur with adequate time to avoid unnecessary costs?)
- Are decision points scheduled for options and alternatives with adequate time for analysis, and to modify current construction or to develop, construct and test the necessary technology alternatives to meet throughput requirements?
- Are infrastructure and support operations specified (HVAC, energy supply, transport, storage), including capacity requirements for each scenario, as well as budget and schedule requirements?
- Are requirements specified for processing tank waste as TRU, including the determination of which tanks will undergo this processing, the technology required, schedule

requirements with necessary regulatory decision points, and determination of alternative disposition and requirements.

1. What are the sources and characteristics of low activity waste at ORP?
 - a. What is the definition and defining characteristics of LAW?
 - b. What are the sources, quantities and expected characteristics (driver radionuclide content, primary chemical constituents, physical nature, special issues [organics? movable?]) of LAW?
 - i. From tank farm
 1. As currently exists in tanks
 2. May be produced with minimal pretreatment
 - a. Solids separation
 - b. Cesium removal
 - c. Other tank farm pretreatment options under consideration?
 3. Produced as a result of tank retrievals and tank closure
 - ii. Produced from pretreatment of HLW
 - iii. Overall, what we are trying to get here is and understanding of: the *major groups of the HLW to be processed; its characteristics & quantities and how that impacts pretreatment options and LAW production (quantities, characteristics, time frames)*
 - c. What are treatment priorities, technical sequences and time constraints?
 - d. What are the requirements (and basis for these requirements) for on-site disposal of treated LAW and where do those requirements reside?
2. What are the advantages and disadvantages of early LAW treatment?
 - a. Impact on WTP lifecycle operating period/cost?
 - b. Impacts on Na processing requirements?
 - c. Impact on SST retrievals?
 - d. Pretreatment needs?
3. What are the advantages and disadvantages of supplemental LAW treatment?
 - a. Impact on WTP lifecycle operating period/cost?
 - b. Impacts on Na processing requirements?
 - c. Impact on SST retrievals?
 - d. Pretreatment needs?
4. What are the system and technology needs to achieve early LAW treatment and/or supplemental LAW treatment?
 - a. What are the advantages/disadvantages/location options/timing options/maturation requirements/cost estimates for different early LAW and supplemental approaches?
 - i. BV (with or without cold demonstration)
 - ii. Early operation of LAW melter
 - iii. 3rd LAW melter
 - iv. Non-glass end products (e.g., ceramic, grout, others)
 - v. Others?

- b. Pretreatment needs, technology options
 - i. Interim Processing System (IPS) currently planned for Sept. 2008 at SRS, consisting of (i) Mobile cesium removal unit (MCU; using centrifugal separations), and (ii) Actinide Removal Process (ARP).
 - ii. Solid separations – (i) spin tech, (ii) others?
 - iii. Others
- c. Potential roles of other technologies
 - i. Elevated temperature leaching of Al (Bayer process; Li-Bayer process; hydrothermal processing [e.g., higher T, P])
 - ii. Fractional crystallization
 - iii. SR?
 - iv. Others?

5. **Primary Options now under consideration**

- a. Do nothing--invest in required infrastructure upgrades, continue some SST retrievals(?), get to WTP operations when we can
 - b. Baseline (how is this defined)?
 - c. IPS + Early LAW (IPS vs. BV)
 - d. BV w/limited pretreatment (solids separations only)
 - e. Demo BV (cold system) or
 - f. One hot line BV without demo
 - g. Additional LAW melter (study in progress to report end of May)
 - h. Grout-based waste forms for a fraction of LAW
 - i. Other options?
6. Where are potential synergies?
- a. Technology maturation and demonstrations
 - b. Reduction in sodium treatment requirements
 - c. Secondary waste treatment requirements
 - d. Increasing WTP throughput
 - e. Early demonstration of achieving some objectives
 - i. Closure of a few tanks
 - ii. Tank retrievals
 - iii. Disposition of LAW
 - iv. Waste form performance demonstration

6.0 Approvals

Original signed 4/3/08

Mark Gilbertson, Deputy Assistant Secretary
Office of Engineering and Technology
Office of Environmental Management
U.S. Department of Energy

Date

Original signed 4/11/08

Shirley Olinger, Manager
Office of River Protection Field Office
Office of Environmental Management
U.S. Department of Energy

Date

Attachment 1. Team Members

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U.S. Department of Energy

Dr. David Kosson
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Professor of Chemical Engineering
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Sciences
Vanderbilt University

Dr. Ian Pegg
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The Catholic University of America

Dr. David Gallay
Program Director
Infrastructure and Engineering Management
Logistics Management Institute

Dr. Ray Wymer
Chemist (Consultant)

Attachment 2. Initial Information Needed

In order to begin an independent review of the technical aspects of this review, the following items are needed:

1. System Plan Rev. 3 Draft
2. System Plan Rev. 2
3. SST Retrieval Sequence Document
4. BNI 3rd Melter Direction Letter
5. Interim Pretreatment System scope package
6. DBVS Integrated Dryer Melt Test Final Test Report
7. ORP Action Plan (Tracking System)
8. Early LAW Study Report
9. DBVS Project Execution Plan
10. DBVS System Description Report